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NATIONAL EMISSION STANDARDS STUDY REPORT. APPENDIX - VOLUME 1. APPENDIXES A- E

National Air Pollution Control Administration
Washington, D. C.

March 1970

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NATIONAL EMISSION STANDARDS STUDY

Report

Appendix - Volume 1

Appendixes A - E

A Report To The Congress Of The United States
By The Secretary Of Health, Education, And Welfare
In Compliance With
Public Law 90-148
Clean Air Act, As Amended

March 1970

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
National Air Pollution Control Administration

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APPENDIX A

DESCRIPTIONS OF METEOROLOGICAL DISPERSION MODEL

APPENDIX A: DESCRIPTIONS OF METEOROLOGICAL DISPERSION MODEL

A.1 INTRODUCTION

A meteorological model, in this report, is a mathematical description of the effects of atmospheric transport and dispersion processes on the behavior of an air pollutant plume from the time the pollutants enter the atmosphere until they reach a known receptor.

Specifically, the model should be capable of defining (a) the motions of the pollutant plume near the source, (b) modifications of the size and shape of the plume as it is transported and dispersed downwind, and (c) based on the quantity of pollutants emitted, the concentration that will result at a known receptor.

In general, a model requires as input: (a) location and physical description of the pollutant source, (b) rate of pollutant emission, (c) specification of meteorological conditions such as wind direction, wind speed, and atmospheric stability and mixing depth, and (d) location of receptor sites. Outputs are estimates of the pollutant concentrations which would occur at the receptor sites.

Most models are based on the Gaussian diffusion equation which is thoroughly discussed by Pasquill (1) and which is supported by an impressive array of theoretical developments and field data. With the dispersion parameters suggested by Pasquill, the equation has consistently provided concentration estimates which are accurate within a factor of 2 to 3. The meteorological model discussed below is based on the Gaussian equation.

A.2 LONG-TERM MODEL

The model discussed by Martin and Tikvart(2) and by Turner(3) and Smith(4) is used to estimate annual average concentrations of air pollutants. It determines, for each source-receptor combination, the pollutant concentration that would occur with each meteorological condition; 480 possible conditions made up of 5 atmospheric stability classes, 16 wind directions, and 6 wind speed classes are assumed. Then, after each concentration is weighted by the relative frequency with which the associated meteorological condition occurs, all weighted concentrations are summed for all source receptor combinations and for all meteorological conditions. As a result, the average pollutant concentration for each receptor is estimated.

This model allows the total impact of a source on air quality over a long period to be ascertained.

It has the advantage of using annual average emission rates and a frequency distribution of meteorological conditions. Thus, the large errors which could be caused by insufficient knowledge of the short period variations in pollutant emissions and meteorological conditions tend to offset each other. The model has been applied to a variety of locales and found to be highly correlated with a wide range of sampled data and to be consistently accurate within a factor of 2 or 3.

A.3 SHORT-TERM MODEL

The adverse effects of air pollutant sources on the air quality must also be examined for short-term conditions (downwash, fumigation, extended periods of calms, air pollution episodes) over periods of up to several days. In many cases where the annual average concentration due to a source is negligible, the short-term concentrations are significant.

The mathematical basis for the short-term model is exactly the same as that for the long-term average model. However, this model, instead of using a frequency distribution of meteorological conditions uses a specific sequence of conditions. For each hour of a hypothetical day with poor dispersion conditions, the wind speed, wind direction, atmospheric stability, and the mixing depth are selected. Then the concentration due to each source at each receptor is determined for each hourly set of meteorological parameters. Finally, the 24 values are summed and averaged to obtain a 24-hour average concentration.

However, the short-term model does not consider the tendency of pollutant concentrations to buildup under poor dispersion conditions; that is, it does not take into account the fact that the pollutants may remain in a relatively small mass of air and be shifted back and forth across an area, especially in a situation where the terrain restrains the air flow. To correct for this omission, the total emissions from the area were allowed to accumulate in a volume dictated by the total volume of air available over the area for a given period of time; appropriate allowances were then made for the transfer of some pollutants out of this volume. The resulting concentrations were added to the model results to complete the estimates of air quality during 24 hours of an air pollution episode.

Since this short-term model has not been tested with air quality data sampled during poor dispersion conditions, no positive statement can be made about its accuracy. However, the accuracy of its basic equations is known and concentrations of the estimated magnitude have been sampled.

A.4 METEOROLOGICAL DATA

A.4.1 Annual

The long-term average concentration model was used with data from two types of locales. The first was open terrain with no major topographic restrictions, similar to the terrain in Kansas. This type is characterized by annual average wind speeds of 8 miles per hour (mph) or greater and a low frequency (15 percent or less) of speeds below 4 mph; the most frequent winds are from the south (see figure A-1). The frequency of inversion conditions, which are accompanied by poor atmospheric dispersion, is 35-40 percent.

The second locale was a valley similar to the type found in the mountainous portions of the United States. It is a pronounced valley (see figure 1-2) approximately 6 miles wide which causes an irregular annual distribution of wind frequencies with pronounced north-northwest and south-southeast directions (see figure A-2). Average annual wind speeds are less than 6 mph, with a frequency of about 35 percent for speeds below 4 mph; the frequency of inversion conditions is 40 percent or greater and cloudy windy conditions, which are favorable for dispersion, occur less frequently than in the open terrain locale.

A.4.2 24-Hour

The meteorological conditions which are conducive to short-term episodes of high pollutant concentrations over periods of 24 hours or longer are: (a) a strong, nocturnal inversion and a light wind which together greatly inhibit the dispersion and permit short-period buildups of pollutants, and (b) daytime mixing depth which limits vertical mixing and confines pollutants to a shallow layer.

In open terrain, these unfavorable conditions last for no more than a day; frequently, high concentrations that occur during the night are substantially reduced during the afternoon by improved dispersion. In the valley, the same unfavorable conditions discussed above contribute to high concentrations. However, these valley locales are subject to prolonged, air-mass stagnations with unfavorable dispersion conditions that may last for 48 hours or more. These conditions tend to cause not only the accumulation of pollutants but also the drifting of the polluted air mass back and forth in the light, shifting winds.

Examples of 24-hour periods, characterized by meteorological conditions similar to those discussed above, were selected for both open terrain and valley locales and were used with the short-term model.

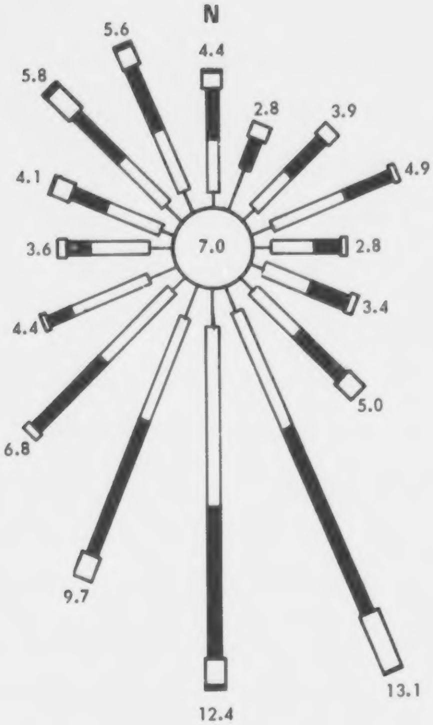


Figure A-1. Distribution of winds in example open terrain locale.

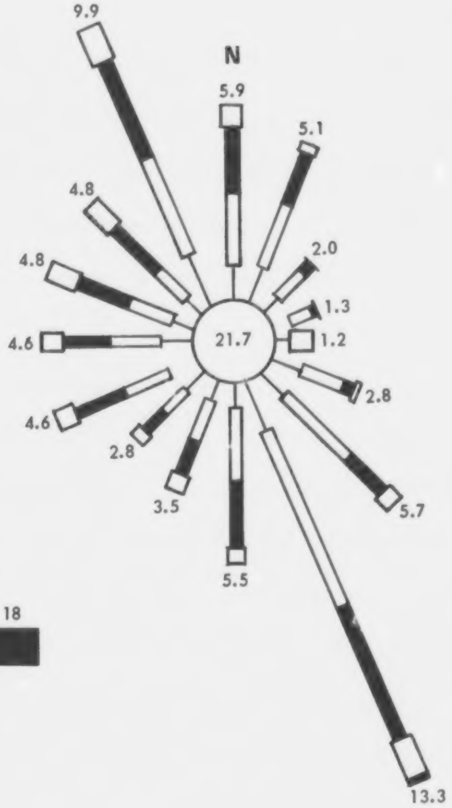
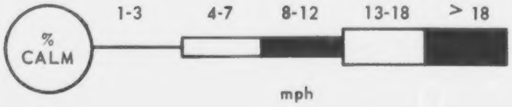


Figure A-2. Distribution of winds in example valley locale.


%
CALM
1-3
4-7
8-12
13-18
> 18
mph

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(1) F. Pasquill, "Atmospheric Diffusion," D. Van Nostrand Company Ltd., London, (1962).

(2) Delance Martin and Joseph A Tikvart, "A General Atmospheric Diffusion Model for Estimating the Effects of One or More Sources on Air Quality," Preprint, U.S. Department of Health, Education, and Welfare, 1968.

(3) D. Bruce Turner, Workbook of Atmospheric Dispersion Estimates, U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, Public Health Service Publication No. 999-AP-26, 1968, Revised 1969.

(4) Maynard Smith, ed., "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents," The American Society of Mechanical Engineers, New York, May 1968.

APPENDIX B

DISCUSSION OF LITERATURE ON HEALTH EFFECTS

APPENDIX B

DISCUSSION OF LITERATURE ON HEALTH EFFECTS

B.1 DISCUSSION OF HEALTH EFFECTS OF SHORT-TERM, HIGH-LEVEL POLLUTANT CONCENTRATIONS

(The references discussed in this appendix correspond, numerically, to the references cited in tables 1-10 and 1-11 of section 1.5 (chapter 1) on health effects of industrial emissions; for convenience, the references are repeated at the end of this appendix.)

B.1.1 Acute Health Effects of 24-48 Hour Concentrations of 200-300 $\mu g/m^3$ Particulate Matter and 0.20-0.30 ppm Sulfur Dioxide

In most of the air pollution episodes reported in this section, concentrations of particulate matter considerably exceeded the range of 200-300 $\mu g/m^3$ (peaks were 1,000-2,000 $\mu g/m^3$ for 24 hrs); however, sulfur dioxide concentrations were in the relevant range of 532 to 1,064 $\mu g/m^3$ (0.20 to 0.40 ppm). Despite the high peak levels of particulate matter, these data were useful because in almost all episodes an excess mortality was observed during the first day or two when the peak concentrations were within the range of 200-300 $\mu g/m^3$.

B.1.1.1 Excess General Mortality

Martin compared daily variations in mortality (expressed as deviations from a 15-day moving average) with variations in particulate matter and sulfur dioxide in London from November 1958 through February 1959.(72) Striking associations were found for peaks in mortality and pollutant levels, and correlation coefficients of 0.61 and 0.52 were found for particulate matter and sulfur dioxide respectively. When daily average concentrations of these two pollutants exceeded 500 $\mu g/m^3$ and 400 $\mu g/m^3$ (0.15 ppm), an excess daily mortality of from 5 to 9 deaths could be expected; this is 4-6 percent above normal. When daily concentrations exceeded 600 μg/m^3 and 532 μg/m^3 (0.20 ppm), an excess daily mortality of from 12 to 13 deaths, or 8-10 percent above normal could be expected.

During a 4-day period in December 1957, concentrations of particulate matter and sulfur dioxide ranged from 400 to 2,330 μg/m^3 and 319 to 1,680 μg/m^3 (0.12 to 0.63 ppm) in London.(73) The average daily mortality during this period was 20 percent above normal. In December 1962, daily particulate matter and sulfur dioxide concentrations in London rose from a baseline of 200 μg/m^3 and 293 μg/m^3 (0.11 ppm) to 2,000 μg/m^3 and 3,465 μg/m^3 (1.3 ppm); during this episode, daily mortality was 13 percent above normal for a 2-week duration.(74) From the latter data, Scott et al. calculated a regression equation to estimate the mortality effect of particulate matter; according to their equation, for every daily increase of 100 μg/m^3 particulate matter (a 7-day moving average) there were 7 additional deaths (also a 7-day moving average) during the episode. Since an average of more than 1,000 deaths a week was available for analysis, factors such as variations in socioeconomic status or smoking habits of the decedents were unlikely to influence the results.

In November 1953, during an air pollution episode lasting six days in New York City,(75) 200 excess deaths (14 percent above normal) occurred. Sulfur dioxide concentrations ranged from 532 to 2,290 μg/m^3 (0.20 ppm to 0.86 ppm) and smokeshade values increased from an average of 2.0 coefficient of haze (COH) units to a range of 4.0-8.4 COH units.

Each of the four reports cited above documented an increase in total daily mortality of from 8 to 20 percent during air pollution episodes in which the concentration of sulfur dioxide exceeded 532 μg/m^3 (0.20 ppm) and particulate matter exceeded 200-400 μg/m^3. In London, where daily deaths usually numbered 120 in 1962 and when both deaths and particulate matter were calculated from seven-day moving averages, a daily excess of 7 deaths was expected for each increase of 100 $\mu g/m^3$ particulate matter.

B.1.1.2 Rise in Infant Mortality

Only one report has associated an air pollution episode with an increase in infant mortality.(76) Early in September 1952, a 3-day period of atmospheric stagnation occurred in Detroit and was associated with a 50-percent increase in infant mortality. Particulate matter concentrations were elevated from an average of 200 $\mu g/m^3$ to a peak of 450 $\mu g/m^3$; no sulfur dioxide data were reported for this episode. However, since no data were given on the usual variation in infant mortality for other years at the same season, little weight can be attached to this isolated finding.

B.1.1.3 Increase in Hospital Admissions for Acute Illness

During the November 1953 air pollution episode in New York City, 4 major hospitals experienced a large increase in clinic visits for upper respiratory tract illness and cardiac disease.(77) Over a 10-day period, the caseload amounted to 62 percent above normal for acute respiratory tract illness and 75 percent above normal for cardiac disease; sulfur dioxide concentrations ranged from 532 to 2,290 $\mu g/m^3$ (0.20 to 0.86 ppm) and particulate matter from 4.0 to 8.4 COH units.

In the December 1957 air pollution episode in London, a rise in sulfur dioxide concentrations from 319 to 638 $\mu g/m^3$ (0.12 to 0.24 ppm) and in particulate matter from 400 to 800 $\mu g/m^3$ was associated with a distinct increase in the daily number of admissions to hospitals for treatment of acute illness.(73) The average daily admissions for December were from 200 to 225; on the first day of the episode, admissions rose to 242 and averaged 277 a day for the 4 days of elevated pollutant concentrations. This December caseload, which was 23 percent above normal, exceeded the peak for the 1957 Asian influenza epidemic, which was one of the most severe of the past 25 years.

B.1.1.4 Aggravation of Symptoms in Patients with Chronic Bronchitis

Symptom diaries were kept by 180 patients in the London area; they assessed their chronic respiratory disease status as "better", "the same", or "worse than usual".(78) The degrees of illness were more closely related to variations in particulate matter and sulfur dioxide than to any other factor during the study conducted from November 1955 through May 1966. There was agreement among the patients that the worsening of their disease was maximal when concentrations exceeded 400 $\mu g/m^3$ and 532 $\mu g/m^3$ (0.20 ppm) for particulate matter and sulfur dioxide. Patients were not unduly influenced by visible pollution since periods of fog and low visibility did not always correspond with elevated concentrations or with deterioration in the conditions of the group as a whole.

The proportion of 90 bronchitis patients who felt worse than usual increased considerably during an air pollution episode in December 1957 in Sheffield, England.(79) From an average of 10 percent of patients who at any one time felt worse than usual, 30 percent felt worse during the December episode. Even though concentrations were not obtained during the winter episode, particulate matter is known to range from 500 to 800 $\mu g/m^3$ in the central part of Sheffield.

B.1.2 Acute Health Effects of 24-48 Hour Concentrations of 150-200 $\mu g/m^3$ Particulate Matter and 0.10-0.20 ppm Sulfur Dioxide

B.1.2.1 Excess General Mortality

In Martin's study of mortality deviations from a 15-day moving average during the winter of 1957-58,(72) a 4-6 percent excess mortality was observed when concentrations of particulate matter exceeded 500 μg/m^3 or sulfur dioxide exceeded 400 μg/m^3 (0.15 ppm).

In a report on air quality criteria for sulfur dioxide in Rotterdam,(80) pollution studies performed were briefly presented without discussion of methodology or detailed results. The authors state that an excess general mortality was observed when daily sulfur dioxide concentrations exceeded 0.18 ppm and that the data suggested some increase in mortality when concentrations exceeded 319 μg/m^3 (0.12 ppm). They also reported that the number of hospital admissions for acute respiratory tract illness increased when sulfur dioxide concentrations rose from 319 to 479 μg/m^3 (0.12 to 0.18 ppm) and that work-absence rates were above normal at these concentrations. No data for particulate matter are given for these studies.

The evidence for the 24-48 hour detrimental effects of lower levels of particulate matter and sulfur dioxide (exceeding 150 μg/m^3 and 266 μg/m^3 [0.10 ppm]) is considerably less firm than for the higher levels previously discussed. However, the overt effects--such as excess mortality and increased hospital admissions for acute illnesses--which have been reported at the lower levels strongly suggest that more common ailments and physiologic disturbances occur during low-level episodes. Slight environmental disturbances are known to aggravate the clinical status of patients with asthma, chronic bronchitis, and borderline congestive heart failure. There is a need to document the reactions of these patients during the kind of air pollution episode which frequently occurs in industrialized metropolitan areas when stagnant meteorologic conditions prevail.

B.2 DISCUSSION OF HEALTH EFFECTS OF LONG-TERM, LOW-LEVEL POLLUTANT CONCENTRATIONS

B.2.1 Chronic Health Effects of Average Yearly Pollutant Concentrations of 125 to 175 μg/m^3 Particulate Matter and 93 to 119 μg/m^3 (0.035 ppm to 0.045 ppm) Sulfur Dioxide

B.2.1.1 Increased Prevalence of Chronic Bronchitis and Emphysema

In comparative studies of the prevalence of chronic respiratory disease in England and the United States,(81) post office van drivers in London and three other English towns were compared with outdoor telephone workers in Washington, Baltimore, Westchester, Los Angeles, and San Francisco. Air pollution monitoring was not carried out specifically for these studies, but it is known from pollutant measurements obtained in these areas that the pollutant gradients of London, English town, U.S. East Coast, and U.S. West Coast are approximately 220 μg/m^3, 200 μg/m^3, 120 μg/m^3, and 120 μg/m^3 for particulate matter and 266 μg/m^3, 53 μg/m^3, 186 μg/m^3, and 27 μg/m^3 (0.1 ppm, 0.02 ppm, 0.07 ppm, and 0.01 ppm) for sulfur dioxide. A corresponding gradient for chronic respiratory disease was observed; 25.7 percent of London post office workers and 21.6-22.2 percent of U.S. telephone workers experienced symptoms of persistent cough and sputum production at ages 40 to 49 years. At ages 50 to 59 years, the differences between the areas were much greater--38.7 percent in London and 25.8 percent in the United States--and the more severe symptoms of disabling chest illness were more common in London than in the English country towns or in the United States. Thus, 11 percent of London workers and 7 percent of U.S. workers experienced episodes of chest illnesses associated with marked aggravation of chronic respiratory disease.

Differences in smoking habits did not account for the observed differences in disease patterns. Symptoms were more common in heavy than in light smokers, and in light than in nonsmokers in all areas. Within these smoking categories, symptoms were most common among the London workers. Interestingly, few of the nonsmokers or ex-smokers in any area had chronic respiratory disease symptoms; thus, internal consistency is given to the results of these studies.

Nonsmoking women 65 years of age and older who were longtime residents of their district in Genoa, Italy, and who were never employed in industry were studied for the presence of chronic respiratory disease symptoms.(82) For comparability of socioeconomic factors, women on welfare assistance and residents in homes without central or local heating systems were excluded. Subjects were chosen from a suburban residential area, a central city residential area, and an industrial area. Particulate matter concentrations were 90 $\mu g/m^3$, 180 $\mu g/m^3$, and 300-800 $\mu g/m^3$ in the suburb, central, and industrial areas respectively; sulfur dioxide concentrations, in the same order, were 66 $\mu g/m^3$, 80-133 $\mu g/m^3$, and 227-346 $\mu g/m^3$ (0.025 ppm, 0.03-0.05 ppm, and 0.085-0.13 ppm). A corresponding increasing gradient of chronic respiratory disease symptoms was found in women of all three areas. From the suburb to the industrial area, the gradient was 16 to 44 percent for winter cough, 6 to 31 percent for sputum production in winter, 23 to 43 percent for shortness of breath, and 18 to 40 percent for rhinitis. In each case, the prevalence of these symptoms among women in the central residential area was intermediate to the other areas.

In another phase of the above study, the prevalence of chronic bronchitis in women who received free medical care was compared in seven districts of Genoa. A distinctly higher prevalence was found where concentrations of particulate matter and sulfur dioxide were in excess of 120 $\mu g/m^3$ and 66 $\mu g/m^3$ (0.025 ppm). For women from 15 to 60 years of age and over, the prevalence in the cleanest areas (less than 120 $\mu g/m^3$ particulates and 66 $\mu g/m^3$ [0.025 ppm] SO_2) was 4 percent; in the intermediate area (180 $\mu g/m^3$and 93 $\mu g/m^3$ [0.035 ppm]), 20 percent; and in the most polluted areas (exceeding 185 $\mu g/m^3$ and 200 $\mu g/m^3$ [0.075 ppm]), 48 percent. No information on the smoking habits of this group was given for this portion of the study in Genoa. However, for women age 60 and older, among whom the proportion of smokers is generally very low, the area difference in chronic bronchitis prevalence rates was still present though the rates for this age group were only 6 percent in the cleanest and 14 percent in the most polluted areas.

The effort to obtain comparability in socioeconomic factors by excluding women on welfare assistance in the first phase of the study and including only women receiving free medical care in the second phase, may have been less than successful. Exclusion of persons on social welfare assistance is not likely to result in comparability between residents of a suburban and industrialized areas. Thus some, though not all, of the differences in symptom prevalence was probably due to the association of lower social class residents living in the most polluted parts of Genoa.

Men who work either in clean or in polluted parts of London were compared to show the frequency with which they experienced one or more episodes of incapacity due to bronchitis lasting four or more days.(83) These episodes were reported to the Ministry of Pensions and National Insurance. Some 3 percent of the workers in the clean area (135 $\mu g/m^3$ particulates and 187 $\mu g/m^3$ [0.07 ppm] SO_2) and 4 percent in the polluted area (355 $\mu g/m^3$ and 400 $\mu g/m^3$ [0.15 ppm]) experienced incapacitating attacks of bronchitis during the one winter season. Pollutant measurements obtained from

October through March reflect the concentrations experienced during the most polluted half of the year. There was no opportunity to collect data on differences in smoking habits or occupational status of the workers in these areas. The levels of air pollution in London do, to a large degree, correlate with socioeconomic factors of the same geographic area.

To minimize contrasts due to socioeconomic factors, groups of towns in 6 areas outside of London were selected for study. Again, a difference of 1-2 percent in the proportion of workers experiencing episodes of incapacity due to bronchitis was observed when clean and polluted areas were compared; unfortunately, even the clean areas had concentrations exceeding 200 $\mu g/m^3$ particulate matter and 133 $\mu g/m^3$ (0.05 ppm) sulfur dioxide. Data on occupational status and smoking habits could not be obtained.

Three areas of Port Kembla, Australia, were compared for differences in respiratory symptom prevalence.(84) Sulfur dioxide concentrations during the summer months--when pollutant levels are highest in the three areas of that city-- were 27 $\mu g/m^3$, 53 $\mu g/m^3$, and 160 $\mu g/m^3$ (0.01 ppm, 0.02 ppm, and 0.06 ppm); particulate matter concentrations were not reported. Corresponding to the sulfur dioxide gradient, a symptom gradient was reported among women for the following symptoms: nasal discharge, head colds settling in the chest, chest illness causing work incapacity, chronic cough, and, in nonsmokers, sputum production. The prevalence of chronic cough in the clean and polluted areas was 8 and 18 percent respectively. Differences in symptom prevalence among men in the three areas were less consistent. Unfortunately, the more polluted district also had a lower proportion of professional, semiprofessional, and administrative occupations than in the clean areas, and no correction was made for possible differences in smoking habits.

A comparison of Canadian veterans living in Winnipeg (which is relatively unpolluted) with veterans living in Halifax, Montreal, and Toronto (which are relatively polluted according to smokeshade recordings that frequently exceed 2.0 COH units) demonstrated a considerably lower sickness rate in the Winnipeg veterans due to chest infections.(85) These veterans were similar in age, occupation, and average cigarette consumption to veterans from the other three cities. The difference in symptom prevalence was corroborated by pulmonary function tests; Winnipeg veterans had the most normal $FEV_{0.75}$ and maximal midexpiratory flow rates based on predicted values for age, height, and sex.

B.2.1.2 Increased Lower Respiratory Tract Illness in Children

Over a 15-year period, 3,100 children born in March 1946 were observed for certain health conditions.(92) The children resided in 2,689 areas of Great Britain; these areas were stratified into 4 air pollution exposure categories on the basis of domestic coal consumption per unit area. In 1962 and 1963, measurements from 179 of the 2,689 areas confirmed the pollutant categorization by coal consumption. Particulate matter concentrations over the 4 categories ranged from 67 $\mu g/m^3$ in the cleanest areas to 281 $\mu g/m^3$ in the most polluted areas, while sulfur dioxide ranged from 80 $\mu g/m^3$ to 239 $\mu g/m^3$ (0.03 ppm to 0.09 ppm). The proportion of children from middle occupational class and working class homes and from upper and lower socioeconomic classes within each occupational class was similar in all four study categories. However, no consistent differences were found in living conditions within the homes of each area.

The frequency of upper respiratory tract infections indicated by the number of colds in the children before 2 years of age and the frequency of colds at 4 and 6 years of age did not differ among the 4 study areas; however, a consistent and increasing gradient for the frequency of lower, and therefore more severe, respiratory tract disease episodes corresponded with the area air pollution exposure gradient. The gradient of lower respiratory tract disease frequency was measured in terms of the proportion of children (a) with the first illness by age of 9 months, (b) with at least one illness in the first 2 years of life, (c) with 2 or more attacks in the first 2 years of life, and (d) with lower respiratory tract illness requiring hospitalization during the first 5 years of life. Children in the most polluted areas experienced a threefold greater frequency in illness episodes, as measured by each of the above characteristics, when compared with children in the cleanest area. Thus, 3.0 percent from middle class families in the cleanest area had more than one attack of lower respiratory tract disease in the first 2 years of life compared with 9.3 percent from the same occupational class in the most polluted area. This illness experience was later reflected in an excess number of primary school absences among children from the more polluted areas.

Similar patterns of respiratory illness were found in Sheffield school children attending the first grade.(93) Four sectors of Sheffield were chosen for study. Pollutant concentrations ranged from 70 $\mu g/m^3$ particulate matter and 109 $\mu g/m^3$ (0.041 ppm) sulfur dioxide in the cleanest sector to 249 $\mu g/m^3$ and 301 $\mu g/m^3$ (0.113 ppm) in the most polluted sector. Persistent coughs, chest colds, and lower respiratory tract illnesses were more frequent in the more polluted sectors. The illness experience for these characteristics was 1-1/2- to 2-fold greater in children from the most polluted sector than from the cleanest sector. Since social class tended to correspond with the air pollution gradient, the investigators compared similar social classes in the 4 sectors and found that most of the disease characteristics were still highly correlated with the air pollution gradient. The two-fold excess illness experience for children in the most polluted area was present even when the effect of social class was isolated.

Bronchitis attacks for children 5-16 years of age living in a polluted area of Kent, England, were from 22 to 34 percent above average when compared with 3 less polluted areas of the same district.(94) No air pollutant data were reported in the referenced study.

B.2.1.3 Increased Frequency of Common Cold and Similar Ailments

The proportion of first grade school children with nasal discharge, with 3 or more colds in the past year, and with perforated ear drum was significantly greater in the more polluted of the 4 study sectors of Sheffield, England, previously described.(93) Likewise, in the Kent study cited above,(94) sinus infection rates were 18 percent above average among children from the most polluted of the 4 sectors.

In a report on air pollution in the Detroit-Windsor area, households in 2 white middle class census tracts of Detroit were selected for study.(76) In the cleaner of the two tracts, particulate matter and sulfur dioxide concentrations were 125 $\mu g/m^3$ and 106 $\mu g/m^3$ (0.04 ppm) when monitored from November 1953 to March 1954 (the time of year when pollution is greatest); in the more polluted census tract, concentrations were 225 $\mu g/m^3$ and 213 $\mu g/m^3$ (0.08 ppm). The monthly rate of sickness was ascertained by interviewers administering a standardized family sickness calendar at 2-week intervals to 90 households in each of the 2 census tracts; the family illness patterns in the 2 census tracts tended to follow the same chronological pattern.

Highest illness rates were reported from October to February during the 2 years of study. The white family illness rate in the more polluted census tract was 25 to 50 percent above the rate for the cleaner tract. These differences were not observed for nonwhite families in clean and polluted census tracts; the air pollution contrast between the latter 2 tracts was considerably smaller than in the white census tract comparisons.

B.2.1.4 Diminished Pulmonary Function

In the previously discussed studies of chronic respiratory disease which compare prevalence in England and the United States,(81) adjustments for differences in age, height, and smoking habits failed to remove the observed superiority of American workers in regard to pulmonary function (FEV_1) performance. This difference was associated with average particulate matter concentrations of 120 $\mu g/m^3$ for U.S. workers and 200-220 $\mu g/m^3$ for British workers. No difference in sulfur dioxide exposure was apparent for the U.S. workers and workers in English towns; average concentrations ranged from 27 to 106 $\mu g/m^3$ (0.01 to 0.04 ppm) in both areas.

The effects of environmental factors on pulmonary function in school children was reported in the Kent study previously cited.(94) In all sex-age groups for ages 5-16, the most important determinant of pulmonary function (peak expiratory flow rate measured with the Wright Peak Flow Meter) was area of residence (i.e., air pollution exposure). The other determinants of importance were past respiratory disease experience, social class, and family size. Pollution concentrations were not reported in this study.

Although pulmonary function was measured in the Sheffield school children study,(93) impaired pulmonary function was demonstrated only for children living in the most polluted study area, where particulate matter and sulfur dioxide concentrations were 249 $\mu g/m^3$ and 292 $\mu g/m^3$ (0.11 ppm).

Canadian veterans from Winnipeg, the cleanest of the four cities studied,(85) were the only group to have unimpaired pulmonary function; these groups were matched for age, occupation, and smoking habits, but data on precise air pollution measurements were not presented.

Differences in pulmonary function performance of children living in clean and polluted regions have also been reported by Japanese investigators, but concentrations in the most polluted regions far exceed the levels relevant to the report.

B.2.1.5 Excess General Mortality

On the basis of air pollutant monitoring at 21 stations, the approximately 120 census tracts of the city of Buffalo were divided into four air pollution strata: less than 80 $\mu g/m^3$, 80-100 $\mu g/m^3$, 100-135 $\mu g/m^3$, and more than 135 $\mu g/m^3$ particulate matter.(86) Each air pollution stratum was subdivided, on the basis of data from the 1960 census, into 5 socioeconomic categories; then mortality rates for all causes were compared in the 20 air pollution strata/socioeconomic categories.

Within each socioeconomic category, a consistently increasing mortality gradient could be documented across the four air pollution strata from the lowest to the highest pollutant categories, for both the 50-69 and 70 and over age groups. For white males, the data suggested that the mortality gradient across air pollution strata was slightly less than the mortality gradient across socioeconomic categories for ages 50 to 69 years; however for ages 70 and over, the mortality gradient across air pollution strata persisted, while the gradient across socioeconomic categories disappeared. Unfortunately, white female mortality rates across air pollution strata within the same socioeconomic categories were not analyzed. As in many retrospective mortality studies, no information was available regarding the usual or last occupation, the smoking habits, or the degree of residential mobility; a large European immigrant population living in Buffalo may have confounded some of the area comparisons across air pollution strata.

The results from this study suggest that when the effect of socioeconomic class is isolated, a 10-20 percent increase in total mortality can be expected in white males at ages 50-69 and 70 and over for each increment increase of 30 percent in particulate matter concentration. These calculations apply to a range of particulate matter from approximately 70 $\mu g/m^3$ to 180 $\mu g/m^3$.

The 120 census tracts in Buffalo were also divided into 3 sulfur oxide air pollution strata.(87) Sulfur oxides were monitored by the lead peroxide candle method. Concentrations in the 3 air pollution strata for a 30-day period were: less than 0.30 mg/cm^2, 0.30-0.45 mg/cm^2, and more than 0.45 mg/cm^2. Again, each stratum was subdivided into 5 socioeconomic categories. Total mortality for white males, age 50-69 years and 70 years and over, showed no association with sulfur oxide levels when the relationship was examined within each socioeconomic category. Again, these data failed to demonstrate an additive or interaction effect between sulfur oxides and particulate matter. Mortality from all causes in areas with low suspended particulate matter did not differ appreciably among areas exposed to high or low sulfur oxide concentrations, nor did mortality differ in areas with high suspended particulate matter and with either high or low sulfur oxide concentrations.

B.2.1.6 Excess Mortality Due to Chronic Bronchitis and Other Chronic Respiratory Disease

Within isolated socioeconomic categories, death rates from chronic respiratory disease among white males age 50-69 years tended to be directly related to the level of particulate matter in the study areas described previously for Buffalo, New York.(86) This relationship was more consistent within each socioeconomic category when death records were searched for any mention (underlying or contributory cause of death) of bronchitis, emphysema, or asthma. The absence of a similar analysis for white females somewhat diminishes the strength of this study; similarly, lack of data on decedents' smoking habits, which are known to be strong determinants of chronic respiratory disease prevalence, weakens the conclusions of the study. With these qualifications, the Buffalo data show a 10-30 percent increase in chronic respiratory disease mortality for each stepwise increment of 30 percent in annual particulate matter concentrations. No consistent association between sulfur oxide levels (as measured by the lead peroxide candle method) and chronic respiratory disease mortality was apparent from the study.(87)

Sulfur dioxide, particulate matter, social index, and population density were studied in relation to the bronchitis mortality of 214 areas of Britain.(88) Social index and sulfur dioxide concentrations accounted for 36 percent of the bronchitis mortality variation within county boroughs, noncounty boroughs, and urban districts; within London boroughs, the social index was the largest statistical determinant of bronchitis mortality. In an attempt to eliminate variations in smoking habits as a factor in the above correlations, population samples were queried; no significant differences in the percent of the sample who regularly smoked or in daily cigarette consumption were found between the different administrative areas. Pollutant concentrations for each administrative area are not presented in the referenced report, and only the correlation coefficients between bronchitis mortality and air pollution are presented for each class of administrative areas. Thus, the pollutant level at which bronchitis mortality effects were observed cannot be stated.

Mortality from all respiratory causes among individuals living in middle level socioeconomic census tracts of Nashville, Tennessee, was positively correlated with the degree of air pollution measured by dustfall, soiling index, sulfur dioxide, and sulfur trioxide.(89) This association which did not hold for mortality from bronchitis, emphysema, or lung cancer was accounted for by deaths from tuberculosis, influenza, and pneumonia; the latter three diseases correlate highly with socioeconomic variations. It is therefore probable that the residual population after exclusion of the highest and lowest socioeconomic census tracts from the analysis still had a significant variation in socioeconomic levels which seemed to be related to the degree of air pollution exposure. Furthermore, important determining factors such as smoking habits and race were not accounted for.

Bronchitis death rates in males age 45-64 and 65 and over were consistently correlated with sulfur oxide levels for each year from 1950 to 1952 in 35 county boroughs of Britain.(90) Sulfur oxide was measured by the lead peroxide candle method. An excess bronchitis mortality, exceeding 120 per 100,000 for males ages 45-64 and 800 per 100,000 for males age 65 and over, was observed in areas where the mean sulfur trioxide of the maximum monthly readings among the different stations for each county borough exceeded 12 mg/100 cm^2. A less consistent correlation was found between particulate matter concentrations and male bronchitis mortality, but no consistent correlation was shown between pollutant measurements and female mortality rates. Smoking habits of decedents were not recorded, and possible differences in socioeconomic levels were not examined.

Bronchitis mortality was higher among men and women of a polluted sector than it was in a clean sector of the Eston Urban District of Northeast England.(91) Concentrations of particulate matter and of sulfur dioxide were 168 $\mu g/m^3$ and 112 $\mu g/m^3$ (0.042 ppm), respectively, in the polluted sector and 80 $\mu g/m^3$ and 69 $\mu g/m^3$ (0.026 ppm) in the clean sector. Average bronchitis mortality rates for age 35 and older in the clean sector were 101 per 100,000 for males and 40 per 100,000 for females. In the polluted sector, bronchitis mortality rates for males and females were 2-1/2 times greater than the above rates. Differences in age composition, smoking habits, and socioeconomic class were found to exist between these 2 sectors, but when adjustments were made for these differences, only 30 to 40 percent of the difference could be explained by these factors even though the observed difference was 150 percent. However, no data are presented to support the latter statements. While data on smoking habits were obtained, these were not used to strengthen the conclusions of this comparison.

B.2.1.7 Excess Mortality from Lung Cancer

In 49 county boroughs of Britain,(88) 45 percent of the variation of lung cancer mortality was statistically explained by population density; when concentrations of particulate matter or of sulfur dioxide were added to this analysis, 51 percent of the variation in lung cancer mortality was accounted for. No differences in smoking habits of the residents of these boroughs were found; however, the intensity of smoking habits of the decedents was not known and may have accounted for higher mortality rates in some boroughs. Pollutant concentrations of the 49 boroughs were not presented in this report.

Lung cancer mortality rates for males age 35 years and over were 104 per 100,000 in the clean sector of the Eston Urban District of England (particulates, 80 $\mu g/m^3$; SO_2, 69 $\mu g/m^3$ [0.026 ppm]) and 180 per 100,000 in the polluted sector (particulates, 168 $\mu g/m^3$; SO_2, 112 $\mu g/m^3$ [0.042 ppm]). This is a difference of 75 percent.(91) Of this difference, 30 to 40 percent could be explained by differences in age, smoking habits, and socioeconomic class, though no data are given to support this assertion. Comparing lung cancer mortality rates of nonsmokers in the two types of sectors, the authors reported 15 per 100,000 for the clean sector and 36 per 100,000 for the polluted sector. This is a difference of 130 percent, of which approximately 15 percent might be accounted for by age and socioeconomic class. The effects of smoking and air poolution on lung cancer mortality were calculated for the Eston and the Stockton Urban Districts; it was concluded that an 85 percent reduction of mortality would occur if mortality rates were reduced to those of nonsmokers, while a 50 percent reduction of lung cancer mortality would occur it mortality rates were reduced to those of rural areas. These data were based in part on the smoking habits of decedents as reported in interviews with relatives of decedents.

No consistent correlation between an air pollution gradient and lung cancer mortality was observed in the Buffalo(86,97) and Nashville(89,98) studies cited previously. However, in each city a positive association between stomach cancer and the air pollution exposure of the population living in each census tract was reported. These data are difficult to interpret because the information was not obtained on the decedents' ethnic origin, which is an important determinant of stomach cancer, and because no specific substances in the measured pollutants have been experimentally associated with stomach cancer.

Air pollution measurements were obtained from 41 monitoring stations in 26 areas of North England and Wales.(95) In these areas, concentrations of particulate matter and 3,4-benzpyrene in these areas correlated highly ($r=0.87$ and 0.86, respectively) with lung cancer mortality in males. In areas where particulate matter concentrations were less than 125 $\mu g/m^3$, age-adjusted lung cancer rates were 35 percent below the overall average for England and Wales, and a progressive increase in rates was observed in areas with higher concentrations of particulate matter and benzpyrene. After correcting for differences in socioeconomic levels (measured as the proportion of the area population in the lowest socioeconomic class), the correlations of lung cancer mortality with particulate matter and benzpyrene were still high ($r=0.72$ and 0.74). No significant correlations of these pollutants with stomach cancer were observed.

A similar comparison was made for lung cancer and air pollution in Belfast, Dublin, Helsinki, Oslo, Copenhagen, Liverpool, North Wales, and Wrexham.(96) Both air pollution concentrations and smoking habits were highly related with lung cancer mortality rates in males and females. For males age 45-54, the correlation coefficient for lung cancer was 0.56

with the average number of cigarettes smoked daily, and 0.64 with particulate matter; for females of the same age, these were 0.98 for smoking and 0.58 for particulate matter. For males age 55-64, the coefficient for lung cancer and smoking fell to 0.27, and for females of the same age, it fell to 0.71; for both sexes, the correlation with particulate matter remained approximately the same as it was for the 45-54 age group.

When both cigarette smoking and particulate matter were treated as cofactors in the analysis of lung cancer mortality rates of these cities, particulate matter appeared to be a significant additive factor with cigarette smoking in the production of lung cancer. Copenhagen and Oslo, with the lowest pollutant concentrations and lowest proportion of the population that smoked cigarettes, had the lowest lung cancer mortality rates, while Belfast and Liverpool were two of the three cities which had the highest pollutant concentrations and highest proportion of smokers, and the highest lung cancer mortality rates. Particulate matter concentrations in Copenhagen and Oslo were less than 70 $\mu g/m^3$, while concentrations in Belfast and Liverpool were 122 and 312 $\mu g/m^3$ respectively. Since the effect of similar smoking habits could not be evaluated from these data, the isolated effect of air pollution on lung cancer mortality cannot be calculated. The results suggested that smoking exerts a stronger effect on lung cancer mortality in the 45-54 age group than in the 55-64 age group but the the effect of air pollution was the same on both groups.

B.2.2 Chronic Health Effects of Average Yearly Pollutant Concentrations of 75 to 125 $\mu g/m^3$ Particulate Matter and 66 to 93 $\mu g/m^3$ (0.025 ppm to 0.035 ppm) Sulfur Dioxide

B.2.2.1 Increased Prevalence of Upper and Lower Respiratory Tract Disease

Of the 3,100 British children observed for 15 years in the study cited above,(92) those residing in the second cleanest (particulates, 91-138 μg/m^3; SO_2, 120-138 μg/m^3 [0.045-0.052 ppm]) of 4 air pollution strata had a greater frequency of lower respiratory tract infections in the first 2 years of life and more frequent hospital admissions for bronchitis and pneumonia than children living in the cleanest air pollution stratum (particulates, 67 μg/m^3; SO_2, 82 μg/m^3 [0.031 ppm]). In the second cleanest stratum, 7.9 percent experienced more than one attack of lower respiratory tract illness in the first 2 years of life compared with 4.3 percent of children in the cleanest stratum. Similarly, data on the study of the Sheffield school children previously cited,(93) showed a higher prevalence of persistent or frequent coughs and more frequent colds and chest colds in 5- and 6-year-old children living in the second cleanest area (particulates, 177 μg/m^3; SO_2, 181 μg/m^3 [0.068 ppm]) compared with those in the cleanest area (particulates, 70 μg/m^3; SO_2, 109 μg/m^3 [0.041 ppm]). Some 23 percent of children in the cleanest area had a history of persistent or frequent coughs compared with 36 percent in the more polluted area; 34 percent of children in the cleanest area had a history of 3 or more colds yearly, while 44 percent in the more polluted area experienced 3 or more colds yearly. The decreasing frequency of colds, coughs, and chest colds in children living in cleaner areas suggests that upper and lower respiratory tract infections are more frequent in areas with concentrations of 75-125 μg/m^3 particulate matter and 66-93 μg/m^3 (0.025-0.035 ppm) sulfur dioxide than they would be in less polluted areas. Since these conclusions can only be made on the basis of extrapolation from observed data, they are only "suggestive" in regard to the strength of the associations.

Asthmatic adults living in the cleanest areas of Nashville, Tennessee, had fewer attacks per year than those living in the 2 more polluted sectors.(99) Concentrations of sulfur dioxide in the 3 sectors were 13 $\mu g/m^3$ (0.005 ppm) or less, 16-32 $\mu g/m^3$ (0.006-0.012 ppm), and 35 $\mu g/m^3$ (0.013 ppm) or more. Concentrations of particulate matter were reported as 1.75 grams (5 tons) or less, 1.75-4.16 grams (5-11.9 tons), and 4.2 grams (12 tons) or more of dustfall per square meter-month (square mile-month) and as a soiling index of 0.350 COH units or less, 0.351-1.099 COH units, and 1.1 COH units or more per thousand linear feet. The frequency gradient from cleanest to most polluted was 30, 44, and 160 asthma attacks per asthmatic person per year. As discussed previously, there is a distinct possibility that air pollution and socioeconomic level were confounded in this analysis, although from other studies it was shown that the proportion of persons with asthma is not greater in the lower socioeconomic classes. However, no data were reported to disprove that the frequency of asthma attacks is greater in lower socioeconomic areas; this may be the case if the attacks can be abated in a population which uses a greater degree of medical care.

B.2.2.2 Excess General Mortality

Mortality rates for all causes were 10 percent lower for white males 50-69 years of age who reside in the air pollution stratum of Buffalo, New York, where the concentration is less than 80 $\mu g/m^3$ compared with a stratum of 80-100 $\mu g/m^3$.(86) This effect was observed within the second lowest, the second highest, and the highest (3 of the 5) socioeconomic categories of census tracts. No census tracts fell simultaneously within the other 2 socioeconomic categories and also the cleanest of 4 air pollution strata. Within the same 3 socioeconomic categories for which data were available, mortality from bronchitis, emphysema, or asthma among white males of age 50-69 was from 10 to 30 percent lower for the cleanest of the above 2 of the 5 air pollution strata. The qualifications to the interpretation of these data should be recalled from previous discussion.

B.2.2.3 Diminished Pulmonary Function

The most important determinant of pulmonary function, reported in the Kent study of school children(94) for children 5-6 years of age was area of residence (which corresponds to air pollution exposure). Past respiratory disease experience, social class, and family size were also determinants in this analysis, but pollutant concentrations were not given.

Pulmonary function (FEV_1) of residents from a relatively clean small town in British Columbia (2.7 $\mu g/m^3$ [0.001 ppm] SO_2 sulfation equivalent and 3.52 grams of dustfall/m^2-mo [10.4 tons of dustfall/sq mi-mo]) was consistently better within each smoking category (nonsmokers, ex-smokers, and current cigarette smokers) than for residents of a more polluted small town in New Hampshire (32 $\mu g/m^3$ [0.012 ppm] SO_2 sulfation equivalent and 12.2 grams of dustfall/m^2-mo [34.9 tons of dustfall/sq mi-mo]). This difference in pulmonary function may possibly be explained by differences in climate or ethnic composition between two widely separated towns rather than by differences in air pollution exposures.

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APPENDIX C

CONTROL COST AND CONTROL SYSTEM ASSUMPTIONS

Equipment categories generally aggregated to determine total investment costs are listed in Table C-1.

Table C-1. TOTAL INVESTMENT COST

1. Basic equipment. Included are taxes and shipping charges with F.O.B. price on the "flange to flange" cost of basic equipment.

2. Auxiliary equipment. Included are the following items essential to the successful operation of a control system but not generally manufactured by gas cleaning equipment suppliers:
   a. Air movement equipment
      (1) Fans and blowers
      (2) Electrical; motors, starters, wire conduit, switches, etc.
      (3) Hoods, duct works, gaskets, dampers, etc.
   b. Liquid movement equipment (in wet collection systems)
      (1) Pumps
      (2) Electrical; motors, starters, wire conduit, switches, etc.
      (3) Piping and valves
      (4) Settling tank
   c. Storage and disposal equipment
      (1) Dust storage hoppers
      (2) Sludge pits
      (3) Drag lines, track way, road way, etc.
   d. Support construction
      (1) Structural steel work
      (2) Cement foundation, piers, etc.
      (3) Insulation (thermal)
      (4) Vibration and/or antiwear materials
      (5) Protective cover
   e. Instrumentation: measure and/or control of:
      (1) Air and/or liquid flow
      (2) Temperature and/or pressure
      (3) Operation and capacity
      (4) Power
      (5) Opacity of flue gas (smoke meters, etc.)

3. Research and engineering design. An allocation of the cost of research and engineering expenditures required for the selection of the specific control system, including such items as: material specifications, gas stream measurements, pilot operations, etc.

4. Installation. Included are the following items when applicable:

   Labor to install
   Cleaning the site
   Yard and underground
   Building modification
   Design contingency
   Inspection
   Field contingency
   Overtime
   Existing facilities protection
   Supervision and engineering
   Field Office charges
   System start-up

Engineering conditions affecting the purchase and installation of air pollution control equipment and those which determine the expected variation for control systems of various efficiencies are given in Table C-2.

Table C-2. CONDITIONS AFFECTING PURCHASE AND INSTALLATION COSTS

Cost Category	Low to Typical Costs	High to Extreme High Costs
Equipment transportation	Minimum distance; simple loading and unloading procedures	Extensive distance; complex procedure for loading and unloading
Plant age	Hardware designed into new plant as an integral part of process	Hardware installed in existing old plant requiring structural or process modification or alteration
Available space	Vacant area for location of control system	Little vacant space, requires extensive steel support construction and site preparation
Instrumentation	Little required	Complex instrumentation required to assure reliability of control or constant monitoring of gas stream
Guarantee on performance	None required	Guaranteed high collector efficiency to meet stringent control requirements
Degree of assembly	Control hardware shipped completely assembled	Control hardware to be assembled and erected in the field
Degree of engineering design	Standard "package type" control system	Control system requiring extensive integration with process, insulation to correct temperature and moisture problem, noise abatement, etc.
Utilities	Electricity, water, waste disposal facilities readily available	Electrical and waste treatment facilities must be expanded. Water supply must be developed or expanded
Collected waste material handling	No special treatment facilities or handling required	Special treatment facilities and/or handling required
Labor	Low wages in geographical area	Overtime and/or high waged geographical area

Table C-2 (Cont.). CONDITIONS AFFECTING PURCHASE AND INSTALLATION COSTS

Cost Category	Low to Typical Costs	High to Extreme High Costs
Auxiliary equipment	Simple draft fan, minimal ductwork	Extensive cooling equipment, ductwork, large motors
Corrosiveness	Noncorrosive gas	Acidic emissions requiring high alloy accessory equipment using special handling and construction techniques

The total annual cost of operating and maintaining the emissions control system includes the annualized capital charges as listed in Table C-3.

Table C-3. TOTAL NET ANNUAL COST

Annual Cost Categories

1. Operating costs.
    a. Utilities needed such as electricity, water, and gas.
    b. Waste disposal operations.
    c. Materials consumed in operating the system.
2. Maintenance costs (including labor and materials).
    a. Replacement of parts and equipment.
    b. Supervision and engineering.
    c. Repairs.
    d. Lubrication.
    e. Surface protection (cleaning and painting).
3. Depreciation: a straight line allocation of total investment cost over the expected economic life of the equipment. For most industries this life is between 10 and 15 years.
4. Other overhead for the control system.
    a. The cost of capital calculated as a percent of total investment cost. The rate varies with different industries but generally falls between 7 and 10 percent.
    b. Property taxes.
    c. Insurance.
    d. Miscellaneous.
5. Process and equipment changes. Included here are modifications made expressly for the sake of reduced emissions as well as fuel switching, fuel substitution, etc.
6. Credits derived from the sale or utilization of gas stream products are particular to each specific industry. The guideline followed is stated in each industry write-up.

APPENDIX D

ANALYSIS OF HYPOTHETICAL NATIONAL EMISSION STANDARDS AND COMPREHENSIVE COST ESTIMATES FOR FOUR MAJOR INDUSTRIES

D.1 INTRODUCTION

To analyze the impact of controlling emissions on the four industries for which control costs were studied in depth, two sets of hypothetical national emission standards are used.

One set consists of uniform national standards under which all plants in each industry are subject to the same stringent emission standard regardless of location.

The other set consists of variable national emission standards under which some plants in each industry are subject to the same stringent standard while the remaining plants are subject to a moderate standard. The purpose of the variable standards is to require a higher degree of control in areas where the detrimental effects of air pollution are greatest. While characteristics of an area such as topography, atmospheric conditions, existing air quality, concentration of emission sources, and type of pollutants are important in determining where air pollution will be more damaging, population concentration is probably the most important characteristic and the most easily measured. Therefore, urban areas, as defined by Standard Metropolitan Statistical Areas (SMSA),(1) are the areas defined here to be those subject to the stringent standards, while the remainder of the country is subject to the moderate standards.

The stringent standard is a composite of regulations from San Francisco Bay Area and New York City. The San Francisco Bay Area regulation limits particulate emissions according to the total weight of the material input to the industrial process; the essence of this regulation is that the larger the process is, the greater the degree of control is required. The New York City regulation limits particulate emissions according to the capacity rating of the fuel-burning equipment; thus the limit becomes progressively more strict with higher capacity installations.(2)

The moderate standard permits twice as much emissions as the stringent standard; for instance, if the stringent standard permits emissions of 4 pounds of particulate per hour, the moderate standard permits 8 pounds.

Allowable emissions for each industrial process considered are discussed in the sections that follow. It must be emphasized that the specified standards in this appendix are designated only for the purpose of illustration of control costs and are not necessarily recommended for any other use.

D.2 GRAY IRON FOUNDRIES

This industry basically consists of small establishments; two-thirds of the industry production comes from plants with fewer than 500 employees.(3) However, about half of the production comes from captive plants owned and controlled by other businesses for the owner's needs; these do not generally produce for the highly competitive open market.

Gray iron foundries range from primitive, unmechanized hand operations to heavily equipped plants in which operators are assisted by electrical, mechanical, and hydraulic equipment. Technological improvements have been slow, but application of control technology has been even slower. In fact, it has been said that equipment manufacturers are almost entirely to be credited for innovations in the industry.(2) Captive plants are more likely to be mechanized and better equipped with emission control equipment than noncaptive plants, but even captive plants owned by large corporations make few capital investments because, compared with their other businesses, foundry operations are often among the least profitable.

D.2.1 Emission Sources

Gray iron foundries, located in almost all urban areas, are likely to be contributors to air pollution. One estimate is that 2-12 percent of the particulate emissions in urban areas originates from gray iron foundries.(4) An estimated 170,000 tons of particulates were emitted in 1966. This was 1.1 percent of the estimated 14.8 million tons from all sources that year.(5) Sulfur dioxide emissions are normally not a problem in gray iron foundries.

The iron-melting process in foundries is the basic source of emissions to the atmosphere, while sand-handling and other processes are the sources of internal foundry problems.

D.2.2 Cupola Emissions

Cupolas, which are vertical cylindrical furnaces, melt over 93 percent of all the gray iron cast in foundries. Because cupola emissions are the most expensive to control, they are the least controlled even though they are the major source of gases and particulates.

Within the furnaces, metal is melted in direct contact with coke, or fuel, by forcing air through openings (tuyeres) near the cupola base; these furnaces range from 18 to 108 inches in diameter. Melt rates range from 1 to over 50 tons per hour. Small foundries generally operate a few hours a day for only 1 or 2 days a week, but some large foundries operate continuously.

Emissions from a cupola include dust, fumes, oil vapors, and smoke. Average particulate sizes are given in table D-1; note that about 25 percent by weight are smaller than 10 microns.

Table D-1. WEIGHT DISTRIBUTION OF CUPOLA PARTICULATES

Particulate Size (microns)	Percent by Weight
0-5	18.1
5-10	6.8
10-20	12.8
20-44	32.9
> 44	29.3

High cupola updraft velocities carry particles of oil vapors, dirt, coke, limestone, fine fumes of iron compounds, and smoke from incomplete combustion of volatiles. These are related to a large degree to the quality of metal used in the charge. Typical output of particulate emissions from an uncontrolled cupola is 17.4 pounds per ton of metal charged; however, it may vary from 10 to 45 pounds per ton of melt. Carbon monoxide (CO) may be greater than 10 percent of the volume of combustion gases; traces of SO_x may also be present.

Many factors affect total quantities of both gaseous and particulate emissions. Among these are the hours of operation, the quantity and quality of metal melted, the ignition system, the ratio of iron to coke, the volume of blast air, the volume of excess air, the stack height, and the size of the charging door.

D.2.3 Electric-Arc Emissions

Electric-arc furnace emissions are, in general, less of a problem to control than cupola emissions. Because the furnaces are mostly used to produce special alloy irons, the quality of material charged is better and freer from dirt and oils. Since no fuels are used in the heating process, the undesirable effects of these on the metal are eliminated. Emissions are primarily metallic fumes; the volume varies from 5 to 10 pounds per ton of metal charged.

D.2.4 Electric Induction Emissions

The emissions from electric induction furnaces are even less of a problem than those from the electric-arc furnaces. Use of clean scrap, minimum exposure of the metal to air while in the furnace, and uniform operation of the furnace usually result in negligible quantities of emissions that would require no air pollution control equipment. The quantity of emissions--primarily metal oxides--is about 2.0 pounds per ton of metal charged; this is less than the emissions from many cupolas having the best controls.

D.2.5 Emissions from Nonmelting Operations

Several foundry operations other than melting produce emissions; these require controls for in-plant housekeeping and protection of personnel. Fortunately, foundries have consistently used highly efficient control equipment within the plants. Thus, the nonmelting operations are not a significant air pollution problem today.

D.2.6 Alternative Emission Controls for Cupolas

A discussion of control alternatives for cupolas must begin with the required efficiency. The required efficiency is a function of process weight and the applicable standard. Process weights (see table D-2) require efficiencies ranging from 70 to 89 percent for the moderate standard and from 85 to 95 percent for the stringent standard.

It is an accepted fact that particles greater than 40-50 microns (μ) can easily be removed by simple control devices, whereas particles less than 10 microns require more complex devices. Because a significant percentage of particles emitted from cupolas is less than 10 microns, emission control requires equipment with the ability to capture a large portion of these small particles. Table D-1 shows that a control system which is ineffective on particles less than 10 microns can achieve at most only 75 percent removal. It follows that a control system must be effective in the 0-5 micron range to achieve overall removals in excess of 90 percent.

Table D-2. CUPOLA EMISSION CONTROL SYSTEM DATA(6)

Cupola size, tons/hour	Air volume, actual cubic feet per minute		Control efficiency required[a]		Pressure drop required on wet scrubber, inches of H_2O	
	With wet scrubbers	With dry collectors	Stringent[b]	Moderate[c]	Stringent	Moderate
2.5	5,876.5	9,247.7	85%	70%	16	7
7.5	17,602.5	27,700.7	88	76	19	10
12.5	29,337.5	46,167.8	89	79	20	11
17.5	41,072.5	64.634.9	90	81	22	13
22.5	52,807.5	83,102.1	91	83	23	14
27.5	64,542.5	101,569.2	92	85	25	16
32.5	76,277.5	120,036.3	93	86	27	17
37.5	88,012.5	138,503.4	94	87	30	18
42.5	99,747.5	156,970.5	95	88	35	19
47.5	111,482.5	175,437.7	95	89	35	20

[a] Percentage particulate removal calculated from process weight standard.

[b] Stringent standard.

[c] Moderate standard.

Of the control equipment presently capable of particulate removals in excess of 90 percent, only high energy venturi scrubbers have been used on cupolas without difficulty.[a] Attempts to use electrostatic precipitators have generally failed. Several foundries, especially in the Los Angeles area, are using fabric filter baghouses with some degree of success and a recent survey by the Department of Commerce (6) disclosed that 43 foundries are using these. Fabric filtration systems, when successful, require afterburners, gas-cooling equipment, high temperature filtration material, and decreased filtration velocities; thus in general, maintenance costs are high and the costs for using fabric filters is greater than for venturi scrubbers in most areas of the country.

Some foundries are currently using multiple cyclone collectors and achieving collection efficiencies up to 80 percent.[b] Overall removal efficiencies depend on air volume and diameter, length, and number of cyclones.

Presently, the control of foundry cupolas is limited. (Tables D-3, D-4, and D-5 show the use of controls.) Only about 15 percent of foundries with cupolas are equipped with some type of control, and part of these are equipped with inefficient wet caps.[c]

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[a] Sterling indicates various operating and performance difficulties with fabric filters and electrostatic precipitators; a discussion of the difficulties is beyond the scope of this report.

[b] This conclusion is based on analyses of data collected in a survey of 67 foundries having control systems for cupolas and discussions with persons who helped identify the weaknesses in the survey data.

[c] A wet cap is a simple collection device consisting mainly of a water-irrigated baffle in the discharge stack. This device is effective in removing some large particles and as a spark arrestor.

Table D-3. GRAY IRON FOUNDRIES WITH CUPOLAS: ESTIMATED DISTRIBUTION OF FOUNDRIES AND CONTROLS BY MELT RATE(6)

	All foundries				
Melt rate, tons/hour	Total foundries	Control systems required[a]	Control systems presently installed		
			MC[b]	WS[c]	FF[d]
0- 4.9	230	248			16
5- 9.9	324	350	3[e]	14	13
10-14.9	276	298	5[e]	13	6
15-19.9	207	224	4[f]	9	4
20-24.9	138	149	3[f]	8	2
25-29.9	23	25		5	
30-34.9	0	0			
35-39.9	0	0			
40-44.9	46	50			2
45-49.9	35	38		9	
TOTAL	1279	1382	15	58	43

[a] Assumes one system can serve two cupolas; some foundries require more control systems.

[b] Multiple cone mechanical collector.

[c] Wet scrubbers.

[d] Fabric filters.

[e] Control insufficient for stringent standard.

[f] Control insufficient for moderate or stringent standard.

Table D-4. GRAY IRON FOUNDRIES WITH CUPOLAS: ESTIMATED DISTRIBUTION OF FOUNDRIES AND CONTROLS BY MELT RATE

Foundries inside SMSA's					
Melt rate, tons/hour	Control systems required	Control systems presently installed			Control systems to be installed
		MC[a]	WS[b]	FF[c]	
0- 4.9	150			14	136
5- 9.9	210	3[d]	8	11	191
10-14.9	179	3[d]	7	6	166
15-19.9	138	2[e]	7	4	127
20-24.9	90	2[e]	6	2	82
25-29.9	15		5		10
30-34.9	0				0
35-39.9	0				0
40-44.9	30			2	28
45-49.9	23		7		16
TOTAL	835	10	40	39	756

[a] Multiple cone mechanical collector.

[b] Wet scrubbers.

[c] Fabric filters.

[d] Control insufficient for stringent standard.

[e] Control insufficient for moderate or stringent standard.

Table D-5. GRAY IRON FOUNDRIES WITH CUPOLAS: ESTIMATED DISTRIBUTION OF FOUNDRIES AND CONTROLS BY MELT RATE

Foundries outside SMSA's						
Melt rate, tons/hour	Control systems required	Control systems presently installed			Control systems to be installed	
		MC[a]	WS[b]	FF[c]	Stringent[d]	Moderate[e]
0- 4.9	98			2	96	96
5- 9.9	140		6	2	132	132
10-14.9	119	2[f]	6		113	111
15-19.9	86	2[g]	2		84	84
20-24.9	59	1[g]	2		57	57
25-29.9	10				10	10
30-34.9	0				0	0
35-39.9	0				0	0
40-44.9	20				20	20
45-49.9	15		2		13	13
TOTAL	547	5	18	4	525	523

[a] Multiple cone mechanical collector.

[b] Wet scrubbers.

[c] Fabric filters.

[d] Foundries requiring additional controls under stringent standards.

[e] Foundries requiring additional controls under moderate standards.

[f] Control insufficient for stringent standard.

[g] Control insufficient for moderate or stringent standard.

D.2.7 Cost of Control

Data describing features of all gray iron foundries that operate cupolas were obtained by the Department of Commerce during 1968. For all plants, the information obtained gave the location while for most plants, it gave the number of cupolas, value of gray iron castings produced, facts on emission controls presently installed, and some data on control costs.

On the basis of the information obtained, a representative sample of 67 foundries with cupolas was selected and visited to obtain extensive data on control systems. The collected data included the following: characteristics of cupola operations; characteristics, types, and numbers of emission control systems already installed; efficiency of emission control; and investment and annual costs. Information on the sizes of cupolas in each plant was used to derive a distribution by size for the total industry. These distributions are reported in tables D-3, D-4, and D-5. The data obtained were also subjected to a series of statistical regressions to relate costs to cupola control factors. The relating of investment cost (by type of collector system) to actual gas volume handled by the control system gave the best fit. For wet scrubbers, costs as a function of two factors, gas volume and pressure drop, were more significant. Sample data were also used to estimate gas volume as a function of melt rate.

These resulting cost functions are linear.[a] The function for annual costs takes into account depreciation and interest expenses on investment costs, maintenance, operating, and other related costs.

The estimated costs of cupola emission control systems are presented in table D-6.

Costs were estimated for each group of plants (by size of cupola);

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[a] Data were insufficient to estimate nonlinear functions.

Table D-6. CUPOLA EMISSION CONTROL SYSTEM COST DATA

Cupola size, tons/hour	Cost of control equipment (thousands of dollars)							
	Investment cost				Annual cost			
	MC[a]	WS[b]	WS[c]	FF[d]	MC	WS	WS	FF
2.5	54.5	103.5	68.9	84.5	12.4	31.2	20.8	25.5
7.5	93.5	179.0	144.4	183.6	21.3	54.0	43.6	55.4
12.5	132.6	246.7	212.1	282.6	30.2	74.5	64.0	85.3
17.5	171.6	318.4	283.8	381.6	39.1	96.1	85.7	115.2
22.5	210.6	386.2	351.6	480.7	48.0	116.6	106.1	145.1
27.5	249.6	457.8	423.2	579.7	56.9	138.2	127.7	175.0
32.5	288.7	529.4	491.0	678.8	65.8	159.8	148.2	204.9
37.5	327.7	604.9	558.8	777.8	74.6	182.6	168.7	234.8
42.5	366.7	678.1	626.5	841.8	83.5	204.7	189.1	254.1
47.5	405.7	752.0	694.3	975.9	92.4	227.0	209.6	294.6

[a] MC--mechanical collectors.
[b] WS--wet scrubbers for stringent standards.
[c] WS--wet scrubbers for moderate standards.
[d] FF--fabric filters.

Source: Costs were calculated with data from survey of 67 plants.

Table D-7. COST OF COMPLIANCE WITH NATIONAL EMISSION STANDARDS FOR PARTICULATES (IN ADDITION TO PRESENT EFFECTIVE CONTROLS)

GRAY IRON FOUNDRIES

Industry	Initial Investment	Annual Cost
Uniform standard	$304,984,000	$92,060,000
Variable standard	$269,863,000	$79,119,000

together these estimates gave the total gray iron foundry cost of compliance with emission standards. In foundries where the variable emission standard required 80 percent or less control, the costs for mechanical collectors were used; costs for wet scrubbers were used in all other cases except for cupolas under 5 tons per hour; in the latter case, fabric filters appear to be less costly. Industry total costs are given in table D-7.

To determine the economic impact for foundries with cupolas of complying with national emission standards, the following assumptions had to be made:

1. That all foundries with cupolas should be included in the calculations of total costs; there is no way of predicting how many, if any, may decide to change to electric furnaces or discontinue operations.
2. That all foundries would, as a general practice, control two cupolas with one emission control system; one furnace would be operated, while the other is idle.
3. That the pattern of the cupola size distribution and gas volume among plants surveyed is representative of the entire industry.
4. That the variable factors other than size, gas volume, and wet scrubber pressure drop are distributed among the entire industry as they are among the plants surveyed.
5. That the wet scrubbers, fabric filters, and the one electrostatic precipitator presently installed can be operated at required emission control levels without significant cost increases and that the mechanical collectors presently installed can provide 80 percent efficiency.
6. That the value received for scrapping the mechanical collectors that need to be replaced by higher efficiency systems is not significant in this study.

D.2.8 Economic Effect

It can be argued that an upper limit to the total cost of imposing emission restrictions on gray iron foundries is the cost, calculated above, to equip existing facilities to control pollution. Basically, this argument hinges on two assumptions: that a producer will not control existing equipment if other alternatives are more economical and, that his judgment of economic effects is accurate. Thus, substituting other materials for gray iron or using other methods to produce gray iron castings would reduce the total cost.[a]

The economic problem concerns the decisions that will be made as a result of the requirement that emissions be controlled. For example, the tendencies to use gray iron castings are summarized by demand-price relationships. The demand is considered inelastic in the short run; an increase in the average price would reduce (other things being equal) the quantity of gray iron cast very little, if any. This judgment is based on the assumptions that most of the castings are inputs for the production of another product, that the cost of the casting is a small part of the value of the final product, but that the casting is a vital part of that final product.[b] If the industry demand is perfectly inelastic, a given quantity would be taken regardless of the price, and the burden of total cost increase would be passed to the users of the castings.

Different foundries that produce castings would experience different economical impacts. For the captive foundries which produce for use within the same firm, the distinction between impact on foundry and the customer has little meaning. Of more importance is the effect on jobbing foundries; because of different cost and capital structures, there would be differing impacts on some even though actual cost increases are fully passed to the customers. The most obvious possibility for a differential economic impact would be the cost increases for the more mechanized (and presumably more productive and larger) foundries to further increase production capacity; these expansions are likely to force smaller, less productive foundries out of business.(3) The logic is that the more mechanized foundry would require a smaller percentage of capital to add pollution control.

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[a] If otherwise still productive capital (e.g., an old foundry) is scrapped rather than control emissions, it is presumed that it is not worth the cost of emission control investment to "purchase" its continued production.

[b] Apparently the final product is often a capital good such as heavy machinery, an automobile or machine tool.

Economic impacts may even affect two apparently equivalent foundries differently. One may decide to control emissions from the old facility; the other may decide to go out of business. One may build a new facility with double the capacity of the old.[a]

Distribution of impact probably would be considered as a random event. However, indications of which foundries will better be able to invest in control equipment or to expand may be obtained by either comparing book value to costs of control or by comparing cash reserve to debt. In other words, firms must have capital "leverage" to finance control equipment.[b] The reaction of firms to economic changes in the past are needed to predict their reactions to the economic impact of pollution control.[a]

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[a] On the average, some must go out of business if others expand capacity and demand does not increase.

[b] Note that the response to a fixed cost per year may be different for a "bookkeeping" cost such as depreciation or the opportunity cost of equity capital and actual dollar costs such as maintenance.

Of the foundries operating cupolas without any type of control, 504 have annual production valued at $500,000 or less for each. The estimated total value of production of the smallest of the 931 plants (with less than $10,000,000 annual production) is around $540,000,000. Average return on sales before taxes is less than 10 percent; this is to say less than $54,000,000 for these 931 plants. Based on the calculated annual cost of emission control for 1279 plants ($92,060,000), it is clear that the industry cannot afford the investment without assurance that the costs can be passed on to customers.

The average price of gray iron castings from smaller foundries would increase on the order of 10 percent. However, this would vary considerably due to the large range of costs per pound for castings. In this highly competitive industry, one foundry cannot risk raising its prices unless other foundries also raise theirs. Because the costs of controls and abilities to distribute these costs will vary among foundries, some certainly will consider going out of business.

If the gray iron foundry is typical of small businesses with severe pollution problems, it is clear that the compliance with emission standards will be an economic strain. Some may be forced out of operation. Modernization and merger are two other alternatives. Industrywide cooperation and understanding will be essential to accommodate the costs and transitions that appear likely.

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[a] These requirements are equivalent to a set of taxes. The investment cost is a lump-sum tax, similar to a franchise tax; the yearly investment costs are similar to a property tax; and the operating costs are similar to a tax on each unit of production. Observed responses to these types of taxes might indicate the response to be expected if emission controls are required.

D.3 PULP MILLS (KRAFT PROCESS)

In 1967, the United State pulp industry produced 36 million tons[a/] of pulp; approximately 23 million tons of this pulp were produced in plants using the sulfate chemical process, normally referred to as the kraft process. About 3 million tons were produced by sulfite mills.[b/] Of the 26 million tons from these chemical process plants (kraft and sulfite), 23 million tons is captive production--that is, pulp used in mills owned or controlled by the pulpmaker. The balance is sold on the market.

The kraft process is the more predominant of the two chemical processes mentioned above and generates more serious air pollution per ton of pulp. At this stage of air pollution investigations, data is not sufficient to develop costs estimates for the sulfite process; therefore, this section deals only with pulp mills using the kraft process.

Capacity of the kraft industry was 29 million tons annually at the end of 1968 with 113 pulp mills reported. These are distributed according to table D-8. The kraft pulping process is the dominant process because of product demands and adaptability to different wood stocks.

The kraft pulp mills contribute an estimated 315,000 tons of particulates and 84,000 tons of sulfur oxides per year. The major portion of effluents to the atmosphere, however, arise from the recovery furnaces. The primary pollutants which result from the recovery process are particulates, hydrogen sulfide, methyl mercaptan, dimethyl sulfide, dimethyl disulfide, and sulfur dioxide. In addition,

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[a/] Combined chemical and mechanical pulp production on an air dry basis.

[b/] An additional 200,000 tons is made in soda pulp mills.

Table D-8. KRAFT PULP INDUSTRY: PLANT SIZE DISTRIBUTION

Plant capacity, tons/day[a]	Number of plants					
	Total		Inside SMSA		Outside SMSA	
	Bleaching	Non-bleaching	Bleaching	Non-bleaching	Bleaching	Non-bleaching
0- 199.9	5	6	2	2	3	4
200- 399.9	9	9	4	4	5	5
400- 599.9	11	13	2	2	9	11
600- 799.9	9	11	1	2	8	9
800- 999.9	6	9	1	2	5	7
1000-1199.9	5	7	1	2	4	5
1200-1399.9	3	4	1	1	2	3
1400-1599.9	0	2	0	1	0	1
1600-1799.9	2	2	0	0	2	2
1800-1999.9	0	1	0	0	0	1
2000-2199.9	0	0	0	0	0	0
2200-2399.9	0	0	0	0	0	0
2400-2599.9	0	0	0	0	0	0
2600-2799.9	1	0	1	0	0	0
Subtotals	51	64	13	16	38	48
Totals[b]	115		29		86	

[a] Capacity is in terms of tons of pulp on an air dry basis (A.D.).

[b] Capacity for one plant is unknown.

the boilers which produce the steam required for the recovery process produce significant pollutants from the burning of bark, coal, and residual fuel oil. Two other sources of significant pollution are lime kilns and smelt-dissolving tanks.

The pulp production process involves cooking wood chips under pressure in a digester with a solution of sodium hydroxide and sodium sulfide (white liquor) that dissolves the lignin binding the cellulose fibers. (See figure D-1.) After digesting or cooking, the entire mixture is blown into a tank where the steam and turpenes flash off and the pulp is washed free of the spent (black) liquor. This weak black liquor is strengthened by evaporation from 15 percent to about 50 percent solids in a multiple effect evaporator and to 65 percent by a direct contact evaporator using exhaust gases from the recovery furnace. This strong black liquor is then burned in the recovery furnace, producing steam and a molten smelt as well as pollutant gases. The smelt contains recovered chemicals for reuse.

The smelt is carried from the recovery furnace into a (smelt-dissolving) tank where it is dissolved with water to form a green liquor; slaked lime is than added to convert it to white liquor and a calcium carbonate precipitate. The white liquor is returned to the digester, and the recovered calcium carbonate is burned in the lime kiln to produce lime for reuse in the caustisizer.

The pulp may be bleached with a weak chlorine solution, washed if required, and then dried. From this point, the pulp is transferred to the papermaking section of the plant.

D.3.1 Emission Sources

The atmospheric pollutants produced at various steps of the process are: digester-venting and blow tank gases (hydrogen sulfide (H_2S), SO_x, mercaptan, dimethyl sulfide, dimethyl disulfide); multiple-

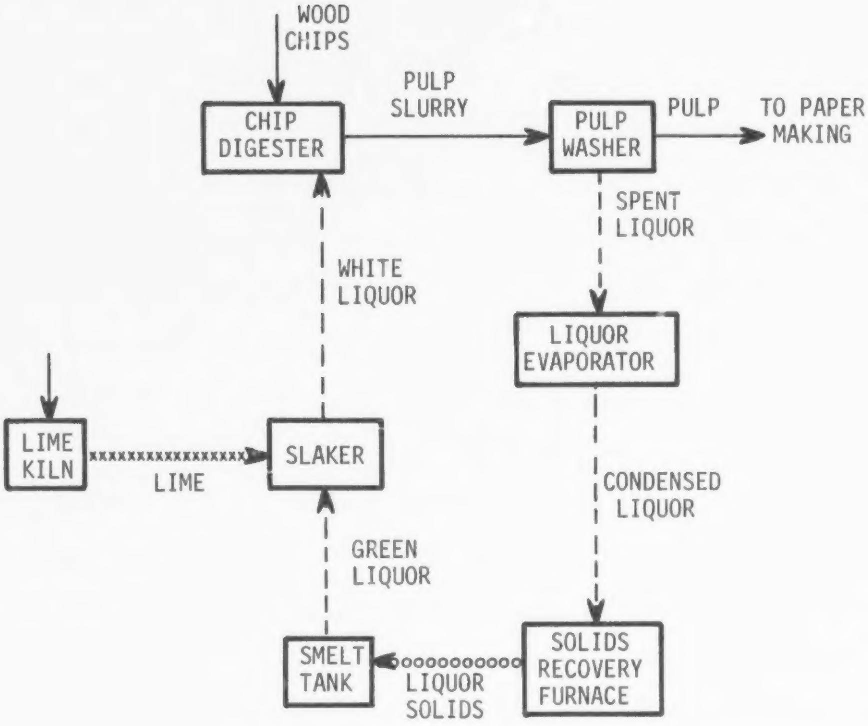
WOOD CHIPS
CHIP DIGESTER
PULP SLURRY
PULP WASHER
PULP
TO PAPER MAKING
SPENT LIQUOR
WHITE LIQUOR
LIQUOR EVAPORATOR
LIME KILN
LIME
SLAKER
CONDENSED LIQUOR
GREEN LIQUOR
SMELT TANK
LIQUOR SOLIDS
SOLIDS RECOVERY FURNACE

Figure D-1. Simplified kraft process diagram.

effect evaporator (mercaptan, dimethyl disulfide, dimethyl sulfide); recovery furnace and direct contact evaporator (particulates, SO_x, H_2S); smelt-dissolving tank (H_2S, mercaptan, dimethyl sulfide, particulates); lime kiln (H_2S, SO_x, mercaptan, dimethyl sulfide, dimethyl disulfide, particulates); turpenes condenser (H_2S, mercaptan, dimethyl sulfide, dimethyl disulfide). In addition, the steam boilers using bark from the pulp wood and secondary fuels produce SO_x and particulates.

The emissions from kraft processes under consideration in this study are particulates and SO_x. It has been shown that sulfur oxides and particulate emissions are negligible in the digester blow system. The major sources of particulate emissions as well as the minor amounts of SO_x are in the chemical recovery system.(7)

In the chemical recovery system, the major sources of particulate matter are the recovery furnace, the smelt-dissolving tank, and the lime kiln. Tables D-9, D-10, and D-11 list the numbers of these processes in the 115 plants considered and give their capacities in terms of outlet gas volumes. Particulate emissions from the multiple effect evaporator are considered completely negligible, but the bark burner is another major source. Table D-12 summarizes unit particulate emissions for the sources considered in this report.

Emissions of SO_x from the recovery furnace and the lime kiln have been observed. Published data indicate that SO_x emissions from the recovery furnace range from 10,000 to 2,120,000 $\mu g/m^3$ (4 to 798 parts per million).(8) The SO_x lost in this operation is process sulfur. However, the source of sulfur in the SO_x emissions from the lime kiln is the fuel used to heat the lime mud; thus the concentrations depend on the sulfur content of the fuel used. There is substantial use of high sulfur content fuel oil for heat in lime kiln operations.(8) Reported SO_x

Table D-9. RECOVERY FURNACES: KRAFT PULP INDUSTRY

Furnace volume 1000 acfm*	Number of furnaces		
	Inside SMSA	Outside SMSA	Total
0- 49.9	0	0	0
50- 99.9	15	45	60
140-149.9	25	74	99
150-199.9	23	70	93
200-249.9	10	28	38
250-299.9	3	9	12
300-349.9	2	6	8
Totals	78	232	310

* Gas flow is taken at the outlet of the direct contact evaporator. Gas conditions vary considerably, but it is assumed that the sample data used has variable factors in representative proportions.

Source: Sample data extrapolated.

Table D-10. SMELT-DISSOLVING TANKS IN KRAFT PULP PLANTS

Effluent volume, 1000 acfm	Number of tanks		
	Total	Inside SMSA	Outside SMSA
0- 4.99	19	5	14
5- 9.99	119	29	90
10-14.99	99	24	75
15-19.99	46	12	34
20-24.99	18	5	13
25-54.99	--	--	--
55 or more	9	2	7
Total	310	77	233

Table D-11. LIME KILNS IN KRAFT PULP PLANTS

Outlet volume 1000 acfm	Number of kilns		
	Total	Inside SMSA	Outside SMSA
0- 9.9	46	12	34
10.0-19.9	109	28	81
20.0-29.9	18	5	13
30.0-39.9	9	2	7
40.0-49.9	--	--	--
50.0-59.9	5	1	4
60.0-69.9	5	1	4
70.0-79.9	--	--	--
80.0-89.9	--	--	--
90.0-99.9	5	1	4
100.0 or more	5	1	4
Total	202	51	151

Table D-12. PARTICULATE EMISSIONS FROM KRAFT PROCESS EQUIPMENT

Process equipment type	Particulate emissions*	
	Uncontrolled, pounds/ton pulp	With existing control, pounds/ton pulp
Recovery furnace	150	21
Smelt tank	20	5
Lime kiln	94	18
Bark boiler	18	4
Total	282	48

* Annual emissions: (24 x 10^6 ton/pulp) 0.57 tons particulates.

concentrations in the lime kiln exhaust gases range from 0 to 425,000 μg/m^3 (0 to 169 parts per million).(9) Finally, minor amounts of SO_x are found in smelt-dissolving tank exhaust gases; the reported range is from 1,330 to 186,000 μg/m^3 (0.5 to 70 parts per million).(9)

D.3.2 Emission Control Alternatives

At present, many kraft pulping operations are controlling particulate emissions to a degree that the value of chemicals recovered is greater than or equal to control costs. The application of electrostatic precipitators to recovery furnace gases is widespread. Similarly, the use of mesh demisters on smelt-dissolving tanks, low energy venturi scrubbers on lime kilns, and mechanical collectors on bark boilers has been reported for a large percentage of the industry. However, few existing control systems have removal efficiencies compatible with those required by the San Francisco process weight rate standard.[a/] Tables D-13, D-14, D-15, and D-16 summarize the removal requirements calculated for use in this study and include estimates of the capital and total annual control costs.

Technically feasible equipment solutions to the problem of achieving satisfactory levels of removal efficiency are available and are in some cases installed at present. Table D-17 lists the type of control equipment reportedly in use at 58 plants. The use of a secondary scrubbing system, most often a medium energy venturi scrubber, after the electrostatic precipitator will achieve satisfactory dust levels in the recovery furnace gases. The use of weak black liquor as the scrubbing fluid is attractive for two reasons: first, the spent scrubbing solution can be returned directly to the chemical recovery system; second, the alkaline black liquor will absorb a

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[a/] Bark boiler removal efficiency requirements, however, were computed using the New York City combustion equipment standard.

Table D-13. EMISSION CONTROL EFFICIENCY AND COSTS: RECOVERY FURNACES

Furnace gas volume, 1000 acfm	Efficiency required, %		Capital cost, $1000 per unit		Total annual cost $1000 per unit	
	Stringent	Moderate*	Stringent	Moderate*	Stringent	Moderate*
25.0	95.0	90.0	92.0	75.0	20.1	14.7
75.0	97.8	95.6	123.0	97.1	48.6	38.3
125.0	98.5	97.0	198.0	165.0	78.1	65.1
175.0	98.86	97.72	258.6	225.8	194.7	91.4
225.0	99.13	98.26	309.0	262.7	130.3	110.7
275.0	99.25	98.50	375.0	321.4	158.0	134.4
325.0	99.35	98.70	420.0	362.5	180.4	155.7

* Moderate efficiency requirement and costs refers to units installed outside SMSA's using the variable pollution control standard.

Table D-14. EMISSION CONTROL EFFICIENCY AND COSTS: LIME KILNS

Kiln gas volume, 1000 acfm	Efficiency required, %		Capital cost, $1000 per unit		Total annual cost $1000 per unit	
	Stringent	Moderate*	Stringent	Moderate*	Stringent	Moderate*
5.0	96.9	93.8	15.9	12.8	6.0	4.9
15.0	97.8	95.6	27.6	22.6	10.5	8.6
25.0	98.2	96.4	38.1	31.6	16.8	13.0
35.0	98.3	96.6	48.0	39.9	23.0	19.1
45.0	98.6	97.2	55.2	46.3	26.6	24.1
55.0	98.75	97.5	61.5	51.8	33.8	28.5
65.0	98.85	97.7	66.0	55.8	37.9	32.1
75.0	99.02	98.04	68.7	58.6	41.2	35.2
85.0	99.09	98.18	72.0	61.4	44.2	37.7
95.0	99.20	98.40	73.8	63.2	47.8	40.8
105.0	99.26	98.52	75.9	64.9	51.7	44.2

* Moderate efficiency requirement and costs refers to units installed outside SMSA's using the variable pollution control standard.

Table D-15. EMISSION CONTROL EFFICIENCY AND COSTS: SMELT DISSOLVING TANKS

Tank gas volume, 1000 acfm	Efficiency required, %		Capital cost, $1000 per unit		Total annual cost $1000 per unit	
	Stringent	Moderate*	Stringent	Moderate*	Stringent	Moderate*
2.5	84.0	68.0	----	----	----	----
7.5	93.2	86.4	13.0	----	6.2	----
12.5	95.2	90.4	17.0	12.9	8.5	7.4
17.5	96.0	92.0	20.0	16.2	10.8	9.7
22.5	96.4	92.8	23.2	18.2	13.1	11.8
27.5-52.5	----	----	----	----	----	----
55.0	98.75	97.5	41.0	35.4	29.7	28.3

* Moderate efficiency requirement and costs refer to units installed outside SMSA's using the variable pollution control standard.

Table D-16. EMISSION CONTROL EFFICIENCY AND COSTS: BARK BOILERS

Boiler gas volume, 1000 acfm	Efficiency Required, %		Capital cost, $1000 per unit		Total annual cost $1000 per unit	
	Stringent	Moderate*	Stringent	Moderate*	Stringent	Moderate*
16	93	86	13.4	9.8	3.5	2.6
24	93	86	18.5	13.4	4.3	3.1
32	93	86	23.0	16.8	5.1	3.7
40	95	90	33.8	27.2	6.1	4.9
48	95	90	40.0	32.2	7.0	5.6
56	95	90	43.8	35.1	7.8	6.3
64	96	92	49.0	38.0	8.6	6.7
72	96	92	53.7	42.5	9.4	7.4
80	97	94	57.5	46.4	10.1	8.1

* Moderate efficiency requirement and costs refer to units installed outside SMSA's using the variable pollution control standard.

Table D-17. CONTROL EQUIPMENT USED IN 1958 (10) (SURVEY OF 58 MILLS)

Recovery furnace stacks		Lime kiln exhaust	
Process	Number	Process	Number
Electrostatic precipitators	50	Wet scrubbers	54
Venturi scrubbers	9	Dry dust collector	1
No equipment	2	No equipment	1
		No lime kiln	2

large percent of the SO_x from the furnace gases. Similarly, low energy venturi scrubbers on smelt-dissolving tanks and medium to high energy venturis on lime kilns, both using spent liquor scrubbing solutions, are considered to be attractive control alternatives.(8) In all three situations, equipment constructed of stainless steel or mild steel with a corrosion-resistant lining is required because of the aggressive nature of the scrubbing solutions.(11)

Satisfactory control of char from bark burners is feasible with multicyclone collectors if they are properly designed to handle the collected char which tends to disintegrate and float through the outlet of a cyclone collector.(12) However, it is reported that redesigned multicyclone systems can radically improve the overall collection efficiencies.

In summary, this report will assume that venturi scrubbers can be effectively applied to recovery furnaces, lime kilns, and smelt-dissolving tanks to control emissions; redesigned multicyclone units can provide satisfactory char removal from the emissions of bark boilers.

D.3.3 Cost of Controls

Basic data to estimate the cost of emission control in the kraft industry has been supplied to the National Air Pollution Control Administration (NAPCA) by Poly Con Corporation. This data consists of the estimated control equipment costs and direct operating costs. The equipment costs covers only the basic control equipment, not piping, wiring, and other such material and labor requirements for installation. To account for these additional cost elements, the equipment costs were factored upward.

For recovery furnaces, the basic equipment costs were multiplied by 3 to obtain an estimate of total investment required; for smelt-dissolving tanks the factor was 2; for lime kilns, 3; and for bark boilers, 2.5.

Annual cost estimates were calculated by adding Poly Con Corporation's estimates of direct operating costs to depreciation and capital charges that together amount to 20 percent per annum of the investment costs.

Most of the particulate matter lost to the atmosphere is valuable process material. Survey data indicates that about 86 percent of the recovery furnace emission is recovered by precipitators or scrubbers. An estimated 81 percent of emissions from lime kilns are recovered and returned to the process. To separate process material recovery from air pollution control, it was assumed that 90 percent recovery control represents the point of delineation. Therefore, the estimated unit costs assume that controls to 90 percent exist or should be installed for material recovery. Only that portion of emission control above 90 percent is considered as cost of compliance with the hypothetical national emission standards.

Installation costs were adjusted to the level of efficiency required by the standard. Required efficiencies and unit costs are given in tables D-13, D-14, D-15, and D-16.

The number and size of bark boilers are unknown. For this study, it was assumed that a typical utility plant would have two boilers--one burning bark, the other coal. Average bark generated was calculated and the estimated cost for emission control equipment was applied.

Costs for controlling emissions from kraft plant utility boilers were based on substituting natural gas for coal. No data is available to define the types and actual quantities of fuel used; however, as a basis for estimating emission control costs, the fuel used was assumed to be coal and the amount required per year was estimated from factors supplied to NAPCA by Environmental Engineering, Inc. The industry costs are presented below in table D-18.

Table D-18. COSTS OF EMISSION CONTROL KRAFT PULP INDUSTRY

Type of process equipment	Estimated cost of control	
	Investment	Annual
Uniform Standard		
Recovery furnace	$ 70,634,000	$ 28,675,000
Smelt tank	5,136,000	2,579,000
Lime kiln	6,244,000	2,786,000
Bark boiler	4,250,000	1,020,000
Utility boiler	---	191,000
Total	$ 86,264,000	$ 35,060,000
Variable Standard		
Recovery furnace	$ 62,504,000	$ 25,419,000
Smelt tank	3,226,000	1,875,000
Lime kiln	5,427,000	2,427,000
Bark boiler	3,340,000	773,000
Utility boiler	---	191,000
Total	$ 74,497,000	$ 30,685,000

D.3.4 Economic Effect

Within the limits of the available data, this section describes the general pattern of the impact on pulp-producing firms of the costs of emission control suggested by the technical analysis and the burden of these costs on the firms involved and their customers.

The emission control costs estimated in this report are for pulp mills. However, it is impossible to consider the making of pulp without also considering the manufacturing of paper and paper products. Over the last decade or so, there has been a marked trend toward vertical integration in pulp and paper; today only approximately 11 percent of the domestic pulp production is for market, and a substantial portion of that is produced by integrated companies that exceed their internal requirements. Over 40 percent of the market pulp is exported and a slightly greater quantity of pulp is imported. The domestic pulp market, with more than half its supply consisting of imports, reflects a small and special aspect of the pulp segment of the industry.

The effects of emission control costs must be considered primarily in terms of the economics of integrated pulp and paper firms. The integration trend has, in fact, progressed to the point where a number of companies that were normally classified lumber or container manufacturers have acquired substantial pulp and paper capacity. The financial strength and profit position of the latter firms is quite different from those which are entirely involved in paper production and radically different from the financial strength of the small number of firms producing pulp only.

Demand for paper and paper products has been rising steadily in recent years at a rate related to, but slightly greater than, the population. The reaction of the industry to increased demand tends to follow a cycle of approximately five years. A few years of heavy investment in new plant and equipment is followed by a period of excess capacity and depressed prices and profits until demand catches up with capacity; this initiates a new wave of expansion and the cycle is repeated. In 1968, paper mills operated at an average of 93 percent of capacity and pulp mills at 89 percent of capacity.(13) Apparently, the industry is in the last phase of the cycle when (a) rising prices occur, (b) profits are above normal, (c) recent investment and startup costs are largely absorbed, and (d) new expansion is ready to begin.

The supply of pulp for the last three years is shown in the table below. Pulp production capacity in 1966 was 40,254,000 tons, and estimated capacity in 1968, based on an average production rate of 89 percent,(14) would be about 42,590,000 tons. In 1968, sulphate pulp accounted for approximately 64 percent of woodpulp production and approximately 63 percent of capacity.

Table D-19. SUPPLY OF WOODPULP IN THE U.S.

	1966	1967	1968
Total pulp production	35,636,268	35,954,923	37,903,000
pulp for own use	31,569,000	31,927,000	n.a.
pulp for market	4,062,000	4,028,000	n.a.
Pulp imports	3,356,502	3,170,288*	3,540,000
Pulp exports	1,572,271	1,720,783	1,902,000

* Imports from Canada accounted for 2,893,421 tons in 1967.

Sources: Data for 1966 and 1967 adapted from Pulp and Paper International, 1968 Review Number, p. 139. Data for 1968 from Survey of Current Business, March, 1968, pp. 5-36.

The trend of the industry is toward an increasing percentage of capacity and production from the sulphate and semichemical processes, while sulphite pulp is remaining nearly constant.

Pulp mills range in size from a capacity of 40 tons/day to 2,600 tons/day, although there are only eight with more than 1,200 tons/day. To illustrate the effects of emission control costs and to reflect economics of scale, costs have been estimated for three mill sizes: 145 tons/day, 500 tons/day, and 1,000 tons/day. Because candidate emission control standards are more stringent for mills within standard metropolitan statistical areas than for those outside SMSA's, costs estimates are presented for both locations; the results are shown in table D-20 below.

The cost per ton of pulp produced varies from a low of $0.86 for a small mill operated outside an SMSA to a high of $1.43 for a medium-sized mill within an SMSA, given the assumed mill structure. These figures are thought to be typical, although an actual plant may experience costs substantially different from those shown depending on the combination of production equipment used.

Mills with a capacity of approximately 500 tons/day appear to be the most common. In modeling a mill of this size, it was assumed that the equipment to be controlled included two recovery furnaces, one lime kiln, two smelt tanks, and two bark boilers. The smaller mill, 145 tons/day, was costed on the basis of one unit of each of these types of equipment. Costs do not increase in direct proportion to the number of units of equipment. The ratio shown between these two examples approximates the relationship expected if a plant of a given size operates with a greater number of smaller capacity units of equipment.

Table D-20. COSTS OF EMISSION CONTROL, SELECTED PLANT SIZES

Mill size, tons/day	Investment cost		Total annual cost[a]		Annual cost per ton produced[b]	
	Inside SMSA	Outside SMSA	Inside SMSA	Outside SMSA	Inside SMSA	Outside SMSA
145	$160,100	$112,600	$ 61,420	$ 42,600	$1.24	$0.86
500	604,400	475,300	240,300	189,200	1.43	1.13
1000	862,000	706,000	381,550	304,000	1.14	0.91

[a] At capacity operation for full year.

[b] Assuming production at 89 percent of capacity, as in 1968.

In estimating the emission control costs for a mill with a capacity of 1,000 tons/day, it was assumed that one recovery furnace, one smelt tank, one lime kiln, and one bark boiler were used. This gives maximum effect to possible economies of scale in pollution control equipment.

Because the mill producing 500 tons/day is the most characteristic of the industry, the highest control costs per ton of pulp produced shown by this example is significant. Without more detailed data, it is not possible to determine to what extent this reflects diseconomies typical of midrange mill sizes. However, it suggests that there may be a competitive advantage for larger mills, many of which are found in large companies operating more than one pulp mill. If, in addition, some of the midrange mills are using more equipment of smaller unit capacity and lower operating efficiency, as seems probable, they may already be operating at lower profit ratios than their large competitors. The competitive impact of the cost differentials indicated may therefore be particularly severe on one segment of the kraft industry.

In assessing the overall burden of the estimated control costs on the pulp and paper industry, the industry's current price and profit position must be taken into account. The industry is experiencing one of its periodic upswings, with improved prices and profits and with production approaching capacity. Nevertheless, the industry profit ratios have tended to be somewhat below the average for all industrial firms in recent years. Return on equity for pulp and paper manufacturers has averaged 9.2 percent over the past ten years.

Incremental costs in the range indicated above would amount to approximately 7 percent of the market value of the pulp produced for firms outside SMSA's and over 9 percent for firms inside SMSA's. Profits on market pulp would, therefore, be sharply reduced in the absence of price increases. The mix of finished products for most integrated firms permits price and profit adjustments, and by shifting to high profit product lines, the effects of additional costs would be cushioned. The firms producing market pulp would be much more severely affected since the market pulp would rise by the full amount of the increased cost. It seems probable under these conditions that the trend toward absorption of pulp producers by integrated firms would be accelerated.

Increased pulp manufacturing costs may result in further upward pressure on the prices of paper and paper products as well. Given the sharply competitive nature of the industry, the differences in financial strength among the firms, and the fact that prices have already risen by approximately 3 to 5 percent on such products as bags and corrugated board, considerable resistance may be expected to further price increases. Thus, net income after taxes may be expected to decline, perhaps in the range of 5 to 10 percent, rather than to continue the increase begun in 1968.

D.4 IRON AND STEEL INDUSTRY

The large quantities of materials handled by the iron and steel industry show that it is a massive segment of the U.S. economy. The industry consumed 135,649,000 net tons of iron ore, 8,885,000 net tons of scrap and mill scale, 14,442,000 net tons of flux, and 54,917,000 net tons of coke to make 87 million net tons of pig iron. The pig iron combined with 62,213,000 net tons of scrap was used in making 127 million net tons of raw steel which in turn was converted into 83,897,000 net tons of finished steel products. Most of this tonnage was produced by a small number of integrated companies that make both iron and steel.

A few small steel plants in the nation are nonintegrated; they generally use electric furnaces. Their steelmaking capacity, which averages about 100,000 tons per plant per year, is low compared with the larger integrated plants. Since most are in areas remote from high tonnage steelmaking and close to specific local markets, the product line usually is limited to reinforcing bars, merchant rounds, and light shapes. Currently, the total annual production of nonintegrated steel plants is estimated at about 2 or 3 million tons.

Included in this study are facilities of 86 companies and 204 plants, which are all the plants in the country reported by the American Iron and Steel Institute to have iron and/or steelmaking furnaces. Table D-21 gives the annual production of raw steel for 1960 and 1967 and projections of about 157 million tons for 1975 and about 180 million tons for 1980.

The major raw materials required to make pig iron are iron ore, coke, limestone, and air. About 70 percent of the metallics charged to blast furnaces are agglomerated products such as pellets which are made at the

Table D-21. CURRENT AND PROJECTED PRODUCTION OF RAW STEEL BY TYPE OF FURNACE (1000 NET TONS)(15)

	Type of furnace				
Year	Open hearth	Bessemer	Basic oxygen	Electric	Total
1960	86,368	1,189	3,346	8,379	99,282
1967	70,690	*	41,434	15,089	127,213
1975	44,000	-	80,000	33,000	157,000
1980	36,000	-	99,000	45,000	180,000

* Included with open-hearth productions.

mine site and sinter which is made at the iron plant. Coke is made at the iron plant by crushing and grinding, blending, and then indirectly heating the coal in long thin ovens. Limestone is received at the steel plant ready for use in blast furnaces; lime is usually prepared in kilns at the quarry site and shipped to the plant ready for use in steelmaking furnaces.

Steelmaking is done in either the open-hearth furnace, the basic oxygen furnace, or the electric-arc furnace. In the rectangular open-hearth furnace, which is comparatively shallow compared to the other two types, the charge materials are heated with various fuels such as oil, tar, natural gas, or combinations of these. In the pear-shaped basic oxygen furnace (BOF), the charge materials of hot metal and scrap are similar to those used in the open-hearth process, but gaseous oxygen is impinged onto the surface of the molten charge at a high velocity so that the heat generated by oxidation of the elements carries the process to completion. The heat to produce steel in an electric-arc furnace is electrical energy; charge materials most often include high quality steel scrap.

In all steelmaking practices, the refined steel is tapped from the furnace into ladles, transported to a casting area, and cast into raw steel forms.

The BOF and the open-hearth furnaces emit large volumes of effluent gases because of large-scale combustion and oxidation processes; electric furnaces emit lower volumes at lower velocities and thus lower the potential for air pollution.

D.4.1 Emission Sources

The industry produces in excess of 2 million tons of particulate matter annually; however, some of these emissions are under control. Important sources of particulates are listed in table D-22. The specific processes to which this section is directed are discussed below.

D.4.2 Coking Process

Over 98 percent of the total production of metallurgical coke, the major source of fuel in blast furnaces, is made by the by-product oven process of converting coal to coke. Valuable ingredients in the volatile gas emitted by heating coal in the absence of air are extracted and recovered in the oven rather than exhausted as contaminants to the atmosphere. After extraction, the gas, which is used for underfiring, for other processes in the oven, as well as for heating in other processes in the steel plant, is free of particulates but usually contains some sulfur compounds.

Steam, flames, smoke, and fine particles of coal are emitted from the oven ports during the charging cycle; during the coking, vapors may leak around the lids which seal the charging ports and around the door

Table D-22. CONTROLLED AND UNCONTROLLED PARTICULATE EMISSIONS FROM SOME STEEL-AND IRONMAKING PROCESSES

Unit process[a]	Emission factor, lbs/ton output	Production rate, tons in 1968	Percent of sources controlling Emissions	Percent level of control of those controlling	Annual emissions, tons	
					Before present controls	After present controls
		51				
Sintering: Windbox	20	51	90	75	1.07	0.73
Discharge	22	51	0	0		
		66.1				
Open-hearth furnace	9.3[b]	66.1	27	90	0.31	0.23
[Open-hearth furnace Battelle emission factor]	[21]	66.1	27	90	[0.69]	[0.53]
Basic oxygen furnace	40	48.6	92	90	0.97	0.17
Electric furnace	10.6	16.4	61	90	0.09	0.04
Total					2.44	1.17

a/ The rate and amount is unknown for coking; the rate for scarfing is 3.0 lbs/ton, but the amount is unknown.

b/ It is assumed that most open-hearth furnaces will be oxygen lanced in the near future.

seals, but characteristics of the emissions from these sources are not available. Thus the particulates originating from all operations in a coke plant are assumed to be about 40 percent from coke, 30 percent from coal, and 30 percent from other mineral dusts normally found in a steel plant.

Leakage of toxic, obnoxious vapors at door and port seals during the early coking stages (when the oven is under some positive pressure) can be minimized by adequate maintenance of the seals. A satisfactory solution to the problem of emission during charging has not been found. The emission during charging and during the early stages of coking (when the ovens are under positive pressure) is considered a serious problem that may not have a solution in the near future.

When the incandescent coke is pushed out of the oven onto an open hopper car, a strong draft is induced in the immediate vicinity, and fine particulates and smoke are blown high into the atmosphere. Good coking practice results in reduced emissions of particulates and smoke, but details on the particle sizes and concentrations of the emissions are not available. The need for control is great.

The open hopper car contains the incandescent coke on a sloping bottom with side gates made of grating. Water sprays are used to deluge and cool the hot coke. The cloud of steam rising in the chimney lifts coke particulates into the atmosphere, but the particulates tend to fall out in the vicinity of the tower. About 87 percent of these emissions occur in the first minute of a 2-minute quenching time. Emissions of particulates into the atmosphere are approximately 6 pounds per load of coke. However, coke quenching is restricted to a locallized fallout problem and hence is a relatively low contributor to area-wide air pollution.

The quenched coke is dumped onto a sloping brick wharf from which conveyors transport it to sizing and screening operations. Although data are not available on the amounts of emission, dusting during coke handling is not a serious problem except in windy weather.

Because of the lack of information on emissions, control techniques, and costs, no estimates can be made for the costs of controls on coking operations.

D.4.3 Sintering

Sintering plants convert iron ore fines and metallurgical dust, including mill scale, into an agglomerated product that is strong enough and large enough for charging into the blast furnace. The iron-bearing materials are mixed with coke dust to form a bed on a slow-moving grate in the form of an endless belt. The bed of ore is raised to its kindling temperature in a gas-fired or oil-fired ignition furnace; a down draft of air keeps the bed burning. A screen catches the sintered material when it is dumped from the traveling grate. Undersized material is recycled. Cooling air is blown over the sinter as it passes through an enclosed cooler on a moving apron or grate. The cooled sinter is dumped directly into cars or conveyors for transport to the blast furnace. Plant capacities range from 2000 to 6000 tons of sinter per day; table D-23 is an estimate of plant distribution. The American Iron and Steel Institute's statistics on raw materials show that an average of about 53 million tons of sinter were charged into blast furnaces annually between 1963 and 1967. Consumption was fairly stable during this period.

Table D-23. SINTERING MACHINES ESTIMATED SIZE AND DISTRIBUTION(15)

Machine capacity, tons of sinter/day	Number of machines Inside SMSA	Number of machines Outside SMSA
2000	12	9
3000	23	3
4000	3	3
5000	1	0
6000	3	0
Total	42	15

Sintering machines process a wide variety of feed materials and produce a considerable amount of emissions. The quantity and nature of the emissions vary from plant to plant. Emissions include dust sucked through the grate bars into the windbox, combustion gases from ignition and firing, and dust generated in screening and cooling operations. Complete combustion during sintering makes it unlikely that the exhaust gas contains unburned hydrocarbons; however, the coke-oven gas used for ignition and the sulfur in the sinter-coke mix contribute to the presence of sulfur dioxide in the combustion products. Sinter dust may contain particles of iron oxides, calcite, iron-calcium silicates, and quartz. Dusts going into the atmosphere from the dust collector are probably similar in composition, but finer in size.

The concentration of particulates in the windbox under the grate during ignition appears to be about 0.5 to 3 grains/scf. According to one report, about 20 pounds of dust per ton of sinter is produced in 225,000 scf of gas per ton of sinter; this gives a concentration of 0.62

grains/scf from the windbox and traveling grate. The size distribution was 3.7 percent over 420 microns, 22.6 percent at 178 to 420 microns, 36.8 percent at 76 to 178 microns, and 36.9 percent under 76 microns. At the discharge from the grate, the size distribution was about 50 percent over 100 microns and 10 percent under 10 microns. At the discharge from the enclosed cooler (at an exhaust volume of 2000 scfm per ton of sinter), the particulate concentration was 5.8 to 6.6 grains/scf. See table D-22 for the total quantity of particulate emissions.

D.4.4 Ironmaking

The blast furnace is a refractory-lined structure about 100 feet high and up to 30 feet or more in diameter at the hearth. Raw materials are charged at the top through a series of seals called bells. Air, preheated in regenerative stoves, is forced through ports called tuyeres arranged around and just above the hearth. The air (usually augmented with oil, gas, oxygen, or steam) rises through the charge and reacts with the hot coke to generate hot reducing gases which, in turn, react with the oxygen in the ore to start the formation of metallic iron. As the charge moves downward into the fusion zone, the iron becomes molten and collects in the hearth. The limestone in the burden reacts with impurities in the ore and coke and forms a molten layer of slag on the pool of iron. Periodically, the hot metal (molten iron) is cast (drawn off) into special enclosed railway tank cars that deliver it to the steel-making furnace. Slag is cast into steel pots and transported to a dump area, or is granulated with water. The gas ascending in the blast furnace is removed at the top, stripped of dust, and then used to fire the regenerative air-blast stoves of the blast furnace. The blast furnace gas is also used as fuel in the powerhouse and other plant operations.

The charging practice for a blast furnace can vary widely. Modern burdens consist of screened ore, sinter, pellets, or a mixture of these. Raw materials are dumped into a receiving hopper at the top of the furnace. In step-wise fashion, the materials are dropped through a series of two or more sealed hoppers; this system minimizes the escape of furnace gas as charges are added and pass successively from one sealed hopper to the next. The particulate emissions attributable to blast furnace charging operations consist of ore dust (Fe_2O_3 and Fe_3O_4), coke dust (chiefly carbon), and limestone dust ($CaCO_3$ and $MgCO_3$). Shrouding at transfer points aids in keeping air pollution to a moderate level.

The cleaned blast furnace gas is used for firing the regenerative stoves that preheat the air blast. Because the gas is burned with excess air, the chimney effluent is relatively free of objectionable particulate or gaseous components, except for sulfur oxides if sulfur-bearing, coke-oven gas is used to raise the caloric value. The gas is cleaned to a dust concentration of less than 0.01 grain/scf to assure that clogging and slagging reactions do not occur when it is used as fuel to fire the regenerative blast stoves. About 30 percent of the gas is used to heat the stoves; the rest is used as fuel for other in-plant heating purposes. It is concluded that control of emissions during smelting in the blast furnace is quite good; therefore, no costs for additional controls on these furnaces are included in this study.

D.4.5 Open-Hearth Steelmaking

With the increase in new basic oxygen furnace (BOF) steelmaking capacity, the percentage of American steel made in open-hearth furnaces has decreased; it was 55 percent in 1967. Some forecasters have predicted the virtual extinction of the open-hearth furnace by 1990. This is fortunate from the standpoint of air quality, because the physical nature of the open-hearth shop and the large volumes of gas involved in the process render control of air quality difficult and expensive. Although the advent of the BOF process has exerted strong pressure favoring retirement of existing open-hearth furnaces, the cost of controlling emissions adequately probably will hasten the retirement of open-hearth furnaces. Table D-24 lists the open-hearth furnaces currently reported by the industry.

The charge to open-hearth furnaces usually includes solid pig iron, iron ore, limestone, scrap iron, and scrap steel. The flame from combustion of oil, tar, coke-oven gas, natural gas, or producer gas travels the length of the furnace and heats and melts the charge.

The composition of the products of combustion was not available for open-hearth furnaces in the United States. It is known that the gas usually contains sulfur compounds from fuels such as oil, tar, and coke-oven gas. Firing with oil is reported to create a lower average dust-loading than firing with tar.

The amount of dust generated varies at different stages of the steel-making process and with different practice. One source gives a dust-loading of 0.78 grain/scf at 60,000 scfm gas flow at meltdown, 1.9 grain/scf at 64,000 scfm gas flow at hot metal addition, 2.70 grain/scf at 66,000 scfm gas flow at the lime boil, up to 5 grain/scf during lancing, and 0.21 grain/scf at 64,000 scfm gas flow during refining. Typical dust-loadings for oxygen-lanced furnaces are estimated to be 20-22 pounds per net ton of raw steel; without oxygen-lancing, about 8 pounds of dust per

Table D-24. IRON AND STEEL INDUSTRY: OPEN-HEARTH FURNACES* (15)

Capacity, tons/melt	Inside SMSA	Outside SMSA	Total
0- 49.9	11	1	12
50- 99.9	17	4	21
100-149.9	43	8	51
150-199.9	155	58	213
200-249.9	95	39	134
250-299.9	36	8	44
300-349.9	34	22	56
350-399.9	23	-	23
400-449.9	18	-	18
450-499.9	-	4	4
500-549.9	7	1	8
550-599.9	5	2	7
600-649.9	1	1	2
Total	445	148	593

* Including acid and basic lined furnaces.

net ton of steel were reported.

The fineness of the BOF particulates makes them difficult to measure. As a result, size analyses have varied widely. One report shows that 95 percent are smaller than 1 micron, with a median of 0.45 micron; another shows that 99 percent are smaller than 0.2 micron, with a median of 0.065 micron. A more recent report gives a median diameter of 0.012 micron. Still another states that 20 percent are smaller than 0.5 micron, 65 percent are between 0.5 and 1.0 micron, and 15 percent are between 1.0 and 1.5 microns.

The only data available on the size distribution of particulate emissions compares a composite sample with a sample taken during the lime boil. About 46 percent of the particles in the composite sample and 77 percent from the lime boil sample were smaller than 5 microns.

The slag pockets, checker chambers, and flues to waste-heat boilers provided opportunities for the dust to settle from the waste gases, and thus served as fairly efficient dust collectors before the advent of oxygen-lancing. The use of oxygen-lancing increases the dust-loading and generates large volumes of fume. Effective control of the emissions is obtained with electrostatic precipitators; venturi scrubbers and bag houses are also being used.

D.4.6 Basic Oxygen Furnace Steelmaking

By the end of 1969, about half of the steel in the United States will be processed in the basic oxygen furnace (BOF), a pear-shaped steel shell lined with refractory brick; the number and capacity of the BOF's are given in table D-25. The charge, which usually consists of hot metal and scrap (in the ratio of about 70 to 30) plus burnt lime, enters through the top and is tilted for tapping. A water-cooled lance, which impinges oxygen at a high velocity onto the surface of the charge, causes violent agitation and intimate mixing of the oxygen with the molten iron, and the rapid exothermic oxidations of carbon, silicon, manganese, and some of the iron supplies the heat to reach the tapping temperature. Impurities in the charge enter the slag. A typical 150-ton furnace produces a batch of steel in about 35 minutes.

Table D-25. IRON AND STEEL INDUSTRY: BASIC OXYGEN FURNACES(15)

Capacity, tons/melt	Inside SMSA	Outside SMSA	Total
0- 24.9			0
25- 49.9	3		3
50- 74.9	2		2
75- 99.9	4		4
100-124.9	10		10
125-149.9			0
150-174.9	6	5	11
175-199.9	4		4
200-224.9	2		2
225-249.9	4	2	6
250-274.9			0
275-299.9	7		7
300-324.9	2		2
Total	44	7	51

Dust concentration, as reported by one source, varied from 2.02 to 4.96 grains/scf. Another source reports it up to 20 grains/scf. The volume of exhaust gas (at combustion temperature) is about 25 times greater than the volume of oxygen blown. The amount of dust per net ton of raw steel was reported in 1959 to range from 14.5 to 27.4 pounds. In 1968, an average of 40 pounds per ton was reported by one plant. Others state that it is 1-2 percent of the weight of the metallic charge.

D.4.7 Electric Furnace Steelmaking

In 1967, electric furnaces (see table D-26) produced 11 percent of the total raw carbon steel in the United States and 36 percent of the alloy and stainless steels. About 59 percent of the electric-furnace heats were carbon steels. Electric induction furnaces melt special alloys on a small scale. If the charge is free of tramp combustibles, emissions from these furnaces are minor and are readily collected in simple equipment.

Electric-arc furnaces are refractory lined cylindrical basins having capacities up to 250 tons. High-current electrical energy is passed through large graphite electrodes extending down through the roof of the furnace. The charge consists of select steel scrap, cast iron scrap, pig iron, and ferroalloys to achieve the desired composition, and flux. Melting is accomplished by the heat of the arc between the electrodes and the charge.

Emissions in the electric-arc furnace can originate either from light scrap that oxidizes readily, from dirty scrap (a major source), or from oxygen-lancing. The emissions consist of fumes from scrap preheating, dust from the melting, and particulates in the off-gases. Information is not available on the nature of the dust from preheating, but dust from

Table D-26. IRON AND STEEL INDUSTRY(15)

Electric-arc furnaces			
Capacity size, tons/melt	Inside SMSA	Outside SMSA	Total
0- 24.9	140	19	159
25- 49.9	49	27	76
50- 74.9	27	5	32
75- 99.9	24		24
100-124.9	18	4	22
125 149.9	5	3	8
150-174.9	2	2	4
175-199.9	4	2	6
200-224.9	4		4
Total	273	62	335
Vacuum induction furnaces			
0- 4.9	30	1	31
5- 9.9	2		2
10-14.9			
15-19.9	1		1
20-24.9			
25-29.9		1	1
Total	33	2	35

operation of the furnace consists of opaque, rounded grains with compositions that depend on the steel being melted as well as the stage of heat. Reports indicate that most (70-90 percent) fumes are below 5 microns in size.(16)

The amount of dust per net ton of steel depends on the condition of the scrap and whether oxygen-lancing is used. Dirty scrap can increase the dust emissions to as high as 30 pounds per net ton of steel, and oxygen-lancing can produce 20 percent of the total emissions in making a heat.

D.4.8 Scarfing

Scarfing is a process for removing defects from the surface of raw steel ingots and other forms. No data is available to estimate emissions or cost of emission control, but some reports do indicate that machine scarfing is a potential air pollution source.

Table D-27. FUELS AND EMISSIONS: IRON AND STEEL PLANT UTILITY BOILERS

Fuel type used	Fuel quantity(15) (10^9 Btu)	Emissons needing control
No. 6 Fuel oil	29,241	SO_2[a/]
Natural gas	115,504	None
Coke oven gas	100,597	SO_2[b/]
Blast furnace gas	121,290	None
Coal	171,108	SO_2 and particulates[a/]
Tar & Pitch	4,899	None
LP Gas	353	None

[a/] See page D-74 on Steam-Electric Power Plants.

[b/] Flue gas contains 0.15 percent SO_2 based on British data reported in reference (16).

D.4.9 Utility Boilers

The iron and steel industry consumes large quantities of fuel to generate steam and electricity. (See table D-27.) In 1967, the steel industry consumed about 42.5 billion kilowatt hours of electrical energy. About 28 percent of this was generated within steel plants. Burning of these fuels produces large quantities of particulate and SO_x emissions; table D-27 indicates which pollutants are emitted from each type of fuel burned. Emissions problems are similar to those in steam-electric plants.

D.4.10 Alternative Emission Controls

The problems of emission control in the iron and steel industry are great. Considerable effort has been applied to develop effective controls at reasonable costs. Because a number of factors vary from plant to plant, uniform solutions have not been found. The analyses in this report and analyses from other sources are briefly summarized below.

D.4.11 Sintering

It is assumed that machines for the sintering process have two separate gas and dust venting systems--one for the sintering strand and the other for the sintered discharge (crushing and cooling of sinter). Literature indicates that three types of control systems are applicable to each of two types of venting systems.

For the sintering process emissions, electrostatic precipitators, fabric filters, and high energy wet scrubbers will remove particulates in excess of 90 percent. For particulate emissions from the discharging process, electrostatic precipitators, fabric filters, and low energy wet scrubbers can be applied for 90 percent or greater control. Table D-28 lists the degrees of control needed for sintering

Table D-28. PARTICULATE CONTROL EFFICIENCY AND COSTS FOR SINTERING MACHINES

Sintering capacity, tons/day	Percent efficiency required		Cost of control* $1000 per unit	
	Stringent standard	Moderate standard	Stringent standard	Moderate standard
	Sintering process			
2000	97	94	884	710
3000	98	96	1283	1058
4000	98.3	96.6	1611	1331
5000	98.6	97.2	1964	--
6000	98.8	97.6	2329	--
	Discharging process			
2000	97	94	262	210
3000	98	96	325	268
4000	98.5	97	371	310
5000	98.7	97.4	399	--
6000	98.9	97.8	433	--

* Cost data were taken from *Costs and Performance of Control Systems and Control Equipment*. Swindell-Dressler Company, Pittsburgh, Pa., March 1969. Adjustments were made in the cost data to account for process size and efficiency of control required. Cost data are for wet scrubber systems whose annual costs exceed those for other systems reported.

machines with estimated costs for the control systems having the greatest cost. The greatest cost system--i.e., the wet scrubber system--was chosen because of the uncertainties and variable factors. This is thought to be the more realistic approach to estimating industry costs.

D.4.12 Steelmaking

All three steelmaking processes require high efficiency control equipment to reduce emissions to meet the hypothetical national emission standards. Electrostatic precipitators, high energy wet scrubbers, and fabric filters have been used either in this country or Europe. In this country in a recent period, the following emission control installations were reported.

	Control type (Number installed)			
Furnace type	Electrostatic precipitator	Wet scrubber	Fabric filter	Mechanical collector
Open-hearth	1	4	0	0
Basic oxygen	2	2	0	0
Electric-arc	0	2	57	1

This report recognizes that while all types of high efficiency devices have been applied, each device has known advantages and disadvantages. Apparently the different conditions and practices in each installation favor one solution for a given furnace type. However, this study recognizes the trends in application of control alternatives which were used for cost-estimating purposes: fabric filters to electric furnaces, and wet scrubber systems to other furnaces.

The particulate emission control requirements are tabulated in table D-29; costs for the control systems used in the study are also tabulated.

D.4.13 Utility Boilers

Sulfur oxide emissions from boilers burning residual fuel oil can be controlled by substituting natural gas or using desulfurized fuel oil. Analyses of costs for fuel substitution with average fuel oil and natural gas gave costs that appeared unrealistic. These were performed without knowledge of relationships between boiler locations and requirements and local fuel prices. Since data were not available to identify types of boilers at specific steel plants, costs of SO_x control were estimated by assuming the cost of desulfurized fuel.

Coke oven gas cannot be feasibly replaced by another fuel. At some point, it must be either consumed or discarded. For this reason the dolomite injection process to control SO_x was assumed to be a reasonable alternative to calculate control costs.

Coal-burning results in particulate and SO_x emissions. To control both, fuel substitution and a process such as the dolomite injection can be used. Because utility boiler operation is of low priority

Table D-29. COST OF CONTROL VERSUS FURNACE CAPACITY

Furnace capacity, tons/melt	Percent efficiency required		Cost of control, $1000 per unit	
	Stringent standard	Moderate standard	Stringent standard	Moderate standard
Open-hearth furnaces[a]				
25	77	54	86	45
75	82	64	252	151
125	85	70	425	269
175	88	76	627	423
225	90	80	836	585
275	91	82	1022	720
325	92	84	1200	807
375	93	86	1413	1035
425	94	88	1619	1221
475	94.5	89	1824	1379
525	95	90	2009	1545
575	95	90	2175	1673
625	95	90	2305	1773
Basic oxygen furnaces[a]				
12.5	98	96	250	206
37.5	98	96	667	549
62.5	99	98	1176	1000
87.5	99	98	1529	1300
112.5	99.3	98.6	1971	1696
137.5	99.3	98.6	2266	1950
162.5	99.4	98.8	2612	2259
187.5	99.4	98.8	2851	2466
212.5	99.5	99	3202	2784
237.5	99.5	99	3450	3000
262.5	99.6	99.2	3859	3360
287.5	99.6	99.2	4118	3586
312.5	99.6	99.2	4329	3770
Electric-arc furnaces[b]				
12.5	77	54	151	79
37.5	82	64	241	147
62.5	86	72	406	263
87.5	86	72	518	335
112.5	89	78	702	480
137.5	89	78	806	551
162.5	92	84	1043	766
187.5	92	84	1161	852
212.5	93	86	1350	998

a/ Cost data were taken from Costs and Performance of Control Systems and Control Equipment op.cit. Cost data cover high energy wet scrubbers for open-hearth and basic oxygen furnaces and fabric filter systems for electric arc furnaces; costs were adjusted to furnace capacity and degree of removal efficiency required.

b/ Cost data were taken from the same source but cover fabric filters and are calculated on the basis of one control system for two furnaces.

in iron and steel plants relative to production processes, it is assumed that these plants would prefer a simpler control alternative. Therefore, cost of control was based on the substitution of natural gas for coal. This is reported to be the current trend in the industry.

The other fuels burned in utility boilers are not sources of significant emissions of particulate matter or SO_x.

D.4.14 Cost of Controls

In general, the cost of emission control in the steel and iron industry was based on estimates of unit process costs developed by Swindell-Dressler Company. Their costs were estimated with data from case files and data supplied by steel companies and equipment manufacturers. Analyses of this data resulted in graphs of principal cost components and factors for others. All data were adjusted to common bases such as 1969 cost levels and Pittsburgh area labor rates. Capital charges were estimated as 10 percent per year; depreciation, 10 percent; and operation time, 7920 hours per year. In these estimates, the equipment was selected and sized to result in an outlet dust-loading of 0.05 grain/scf of gas.[a]

Swindell-Dressler estimated the capital investment and annual costs for two or three sizes of each process and for each type of control system applicable to each process. A tabulation of the estimates and their bases is given in table D-30.

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[a] For estimates needed in this study, costs were adjusted to reflect the dust loading required by the candidate standards.

Table D-30. BASES OF SWINDELL-DRESSLER CONTROL COST ESTIMATES

Feature	Process			
	Sintering Plant	BO Furnace	OH Furnace	Electric-arc Furnace
Number of process sizes included	2	3	3	3
Number of control types included	3	3	3	3
Installation basis	Existing Plant	New Plant	Existing Plant	New Plant
Other	-	-	-	Design to handle 2 furnaces alternately

Control costs of emissions from utility boilers are summarized in table D-31. In cases where investments are needed to convert boilers to fire natural gas or to install equipment for dolomite injection, the number of boilers was estimated on the basis of the proportion of consumed fuel heat value. It was assumed that all plants in the study (205) had one boiler burning oil, gas, or coal.

Table D-31. UTILITY BOILER EMISSION CONTROL COSTS: IRON AND STEEL INDUSTRY

Fuel type used	Number of boilers*	Means of control of emissions	Estimated cost of control ($1000)	
			Investment	Annual
No. 6 fuel oil	19	Use of desulfurized fuel oil	--	1,754
Coke oven gas	38	Use of dolomite injection to control SO_2	2,950	1,885
Coal	110	Substitution of natural gas	440	13,757
TOTAL COSTS			3,390	17,396

* Estimated

In general, to make cost calculations, it was assumed that all presently existing furnaces and other facilities should be included. While some furnaces may be retired in the next few years, these probably will be replaced with other furnaces requiring control; furthermore, retirement of some may be hastened by restrictive costs of emission control. Thus, calculation of cost estimates on all existing furnaces more adequately reflects the potential costs that iron and steel companies face at this moment.

D.4.15 Economic Effect

To illustrate the impact of control costs on steel firms and to indicate the probable effects of these costs on the price structure, the steel industry was divided into integrated and nonintegrated firms.[a] Integrated firms are those which produce at least a part of their own iron, convert iron to steel, and process the raw steel into saleable shapes. The 21 companies in this group account for more than 90 percent of the total steel production of the United States and an even higher percentage of the basic grades of carbon steel. The remaining 65 companies of the nonintegrated group are almost entirely engaged in making a wide variety of specialty steels such as tool steel, stainless, and special alloys by using ingot steel purchased from an integrated firm as the basic input. Thus this analysis of impact and burden has been based almost entirely on data from integrated steel firms.

Although none of the integrated steel firms would be classed as small in comparison with those of other industries, there is a large variation

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[a] For a more complete discussion of the structure of the iron and steel industry see: Economic Aspects of Control of Air Quality in the Integrated Iron and Steel Industry. Final Report, Contract No. Ph 22-68-65, Department of Health, Education, and Welfare, National Air-Pollution Control Administration, prepared by Battelle Memorial Institute, March 31, 1969.

Table D-32. COST OF ADDITIONAL CONTROL: IRON AND STEEL INDUSTRY

Uniform standard			
	Present controls	Cost ($1000)	
Process	assumed[a/] Percent Level	Investment	Annual[a/]
Sintering	None[b/]	88,000	33,000
Steelmaking			
open-hearth	90%	365,000	141,000
basic oxygen	92 90%	79,000	30,000
electric-arc	61 90%	22,000[c/]	7,000

[a/] Credit for existing controls is taken into account; where higher efficiency is required, only cost for the additional degree of control is costed. For electric-arc furnace, existing control systems were assumed to be completely adequate.

[b/] It was assumed that most have mechanical collectors to recover a portion of potential material lost; however, it was further assumed that such devices would not significantly reduce the cost of compliance with the candidate standards.

[c/] Most additional controls needed were estimated on the basis of one control for paired furnaces; these controls numbered 57. Where odd furnaces exist (16 total) one control system at adjusted cost was included for each furnace.

Table D-33. COST OF ADDITIONAL CONTROL: IRON AND STEEL INDUSTRY

Variable standard		
	Cost ($1000)	
Process	Investment	Annual
Sintering	84,000	31,000
Steelmaking		
open-hearth	331,000	129,000
basic oxygen	56,000	22,000
electric-arc	21,000	7,000

in size within the industry. Output from individual companies in 1967 (the latest year for which complete figures are available) ranged from under 1 million tons per year to over 30 million tons per year; the 2 largest firms accounted for approximately 40 percent of output and along with 8 other firms produced over 75 percent. Individual company sales ranged from approximately $85 million to more than $4 billion in 1967, and net income after taxes ranged from a loss of nearly $7 million for one company to a profit of $172 million for another.

The true profit position of the steel industry is difficult to establish clearly. The net income after taxes of any one firm may vary substantially from year to year as a result of the influence of a number of factors:

1. The heavy "startup" costs usually associated with major investments may reduce profit. This was apparently a significant factor for some firms in 1966, 1967, and 1968.

2. Those firms producing a narrow range of saleable shapes and selling primarily to one industry, such as the automobile industry, may experience severe profit swings due to changes in the market.

3. Some firms have been particularly affected by competition from imported steel products. Import of products such as barbed wire has been much more significant than import of others such as tool steel.

4. Stockpiling of steel by consuming industries in years of threatened steel strikes has caused wide variation in profits from year to year.

5. Although total profits tend to increase with increased sales, profit as a percentage of sales or as a rate of return on capital may be optimum at production rates around 50 percent of capacity, declining as production rises above this level.

6. Changes in accounting practices may change reported earnings from one year to the next. This was particularly true in 1968 when many firms changed from rapid depreciation to straight-line depreciation; as much as 50 percent of their 1968 profits reflected this change.

7. Calculation of a rate of return on capital is complicated by the existence of substantial obsolete plant equipment in some firms which is not in operation and may be inoperable but still carried in the accounts.

The impact of the cost of full control of air pollution on steel manufacturing firms is most meaningful in terms of what it would be for individual companies. This will depend upon the size and type of equipment used and the profit position of the firm. To illustrate the range of impact, three hypothetical firms are described which do not represent actual firms. Instead, these are examples designed to represent characteristics common to actual firms and to reflect conditions in the industry in 1967.

Hypothetical Firm #1.

Production: 7.5 million tons, raw steel; 6.4 million tons, finished steel; 9.036 million tons capacity.

Annual Revenue: $1,087,000,000 sales; $100,000,000 net income before taxes; $75,000,000 net income after taxes.

Equipment:

Number	Type	Capacity
3	Sintering, single strand	3,000 tons per day
2	Open-hearth furnace	550 tons per heat
1	Open-hearth furnace	500 tons per heat
5	Open-hearth furnace	450 tons per heat
3	Open-hearth furnace	350 tons per heat
1	Open-hearth furnace	275 tons per heat
3	Open-hearth furnace	250 tons per heat
3	Open-hearth furnace	190 tons per heat
2	Basic oxygen furnace	280 tons per heat

Data for firm #1 reflect the operating conditions of firms with approximately two-thirds of their productive capacity in the form of older open-hearth furnaces to which have been added several basic oxygen furnaces, accounting for one-third of capacity, the result of substantial investment programs over the last decade. Total productive capacity, annual production, revenue, and profit are scaled to the levels characteristic of the larger firms of the industry.

For this firm with 2 basic oxygen furnaces and 18 open-hearth furnaces, as listed above, the annual cost of air pollution control equipment would total $12,073,000. If it is assumed that this firm is already (in 1967) using control equipment in proportion to the industry as a whole, the cost of improved control would be reduced by 27 percent for the open-hearth furnaces and by 92 percent for the basic oxygen furnaces. Total incremental annual cost then would be $6,745,000, and net income before taxes would therefore be reduced to approximately

$93,255,000. Assuming that the reduction in taxes resulting from this decrease in net income would be in proportion to the overall tax pattern shown by net income before and after taxes, net income after taxes would be reduced to $69,941,000, a decrease of 9.3 percent.

The incremental annual cost of air pollution control for this firm would amount to an average of $1.05 per ton of finished steel, which had an average price in 1967 of approximately $170 per ton.

A firm of the size and type hypothesized here would probably use up to three sintering machines. This equipment is probably already controlled to recover some of the particulate emissions; however, if such control were lacking, control cost for 3 machines of the capacity indicated would be approximately $1,782,000 per year. If this were added to the costs for furnace control, the combined costs per ton of finished steel would be increased to $1.33.

The impact of air pollution control costs indicated for this firm represents a probable maximum, when using the cost method indicated and the assumed production pattern. Such a firm would probably be already using more control equipment on its open-hearth furnaces than was assumed in these calculations. The tax effect of such added costs might also be larger than shown.

Hypothetical Firm #2

Production: 1.86 million tons, raw steel; 1.58 million tons, finished steel, 2.24 million tons capacity.

Annual Revenue: $241,800,000 sales; $12,090,000 net income before taxes; $9,910,000 net income after taxes.

Equipment:

Number	Type	Capacity
1	Sintering, single strand	3,000 tons per day
1	Open-hearth furnace	500 tons per heat
2	Open-hearth furnace	450 tons per heat
1	Open-hearth furnace	275 tons per heat
3	Open-hearth furnace	250 tons per heat

Firm #2 represents firms using only open-hearth furnaces. Actual firms of this type are declining in number due to the advantages of the basic oxygen furnace. Since firms still using only open-hearth furnaces vary widely in size, this hypothetical firm was scaled to represent medium size firms.

Air pollution control would cost approximately $3,329,000 per year for the 7 furnaces listed. If it is assumed, as in the previous example, that the firm already effects 27 percent control, the incremental control cost required to bring this up to the standard would be approximately $2,430,000 per year. The impact of this additional cost would reduce the 1967 net income after taxes to $7,918,000, assuming a tax effect equal to the relationship of net income before and after taxes.
This would be a reduction of 20 percent in net income after taxes. The incremental annual control cost may also be expressed as an average of $1.54 per ton of finished steel.

Assuming, as in the previous example, that additional control is indicated for the sintering machine such a firm might employ, an additional required annual cost of $549,000 would raise the impact to $1.91 per ton of finished steel.

Again, as in the previous example, it is probable that the indicated impact of air pollution control cost represents a maximum figure for the type of equipment and company operations hypothesized.

Hypothetical Firm #3

Production: 2.004 million tons, raw steel; 1.703 million tons, finished steel; 2.325 million tons capacity.

Annual Revenue: $282,600,000 sales; $20,065,000 net income before taxes; $15,049,000 net income after taxes.

Equipment:

Number	Type	Capacity
2	Basic oxygen furnace	120 tons per heat
1	Electric furnace	185 tons per heat
3	Electric furnace	125 tons per heat
2	Electric furnace	117 tons per heat
2	Electric furnace	70 tons per heat
4	Electric furnace	25 tons per heat
1	Electric furnace	19 tons per heat
3	Electric furnace	16 tons per heat
2	Electric furnace	12 tons per heat
1	Electric furnace	6 tons per heat

Firm #3 is designed to be representative of firms that have retired all open-hearth furnaces and that produce with approximately one-half basic oxygen furnace and one-half electric furnace capacity. Air pollution control cost would be approximately $1,522,000 per year for two 120-ton basic oxygen furnaces and $1,280,000 for the electric furnaces specified. If it is assumed, as in previous examples, that control is now in effect for 92 percent of the BOF capacity and 61 percent of the electric furnace capacity, the incremental annual control cost to achieve the specified standard would be $623,000. The impact of this cost on net income after taxes may then decrease 6 percent to $14,169,000, assuming a tax saving in proportion to the ratio of before and after tax net income indicated above. At the output specified, this would be an average cost of $0.37 per ton of finished steel.

In this example, the large number of small electric furnaces is responsible for a higher cost per ton of finished steel than in the other hypothetical firms. This could probably be reduced by designing control equipment to serve several furnaces simultaneously.

D.4.16 Burden of Control Costs

The iron and steel industry is generally characterized as having administered prices; that is, prices are usually set by the largest firm acting as price leader and reflect the market power typical of firms subject to oligopolistic competition.(17,18) This means that prices tend to be held unchanged for considerable periods in the face of fluctuations in market demand until a substantial change in price appears warranted. Such a change, usually initiated by the firm acting as the price leader, is then followed by changes in all of the firms in the industry. This suggests that the varying cost of air pollution control for different firms may require that some absorb a greater share of the cost than others but that the cost differences will not be reflected in price competition.

The primary question is whether the cost of required air pollution control would be passed on to consumers through a revision of the administered price structure of the industry. To the extent that this were done, the burden of these costs upon the stockholders of the firms, as recipients of earnings, would be largely eliminated. Ability to shift these costs depends upon the competitive position of the U. S. steel industry as a whole relative to foreign producers who share the U. S. market, and upon the market prospect for products made by the major users of steel.

These prospects are generally favorable to a steel price increase over the next three years, but some additional inflation of the aggregate economy seems inevitable. Considerable expansion is forecast for the automobile industry, for construction, and for other major steel using industries. In addition, an informal agreement was concluded in December 1968, with the Japanese Iron and Steel Exporters Association and with the Association of Steel Producers of the European Coal and Steel Community to limit exports to the United States over the next three years.(19) If this agreement is honored, steel imports from these nations will be reduced in 1969 by 2 1/2 million tons from the 1968 level and will be permitted to rise no more than 5 percent per year in 1970 and 1971. Combined with rising prices for imported steel, this would seem to reduce substantially the competitive effect of imports.

It seems reasonable, therefore, to suggest that increased costs in the range of $0.35 to $2.00 per ton of finished steel may be passed on to consumers in the form of price increases if they are spread over a number of years. A price increase in this range would then diffuse into the economy in amounts which would be relatively small in the prices of finished consumer goods; however, this price increase would contribute marginally to the expected general inflationary pressure.

D.5 STEAM-ELECTRIC POWER PLANTS

Conventional steam-electric plants are the principal source of power for the electric utility industry in the United States. They generate approximately 80 percent of the industry's output.(20) Particulates, sulfur oxides (SO_x), and nitrogen oxides emitted from boilers are the major pollutants. The costs of effective controls designed to reduce, or even minimize, air pollution could add significantly to costs of power generation.(21)

D.5.1 Emissions Sources

In general, the quantity and characteristics of power plant emissions are determined by the type of fuel and to some extent by the method of firing. In 1967, the steam-electric generation industry consumed 274 million tons of coal, 2,739 billion cubic feet of gas, and 156 million barrels of oil; the total is the equivalent of 437 million tons of coal.(22) Coal accounts for 64 percent of the total fuel; gas, 27; and oil, 9.

As a consequence of burning these fossil fuels, tremendous amounts of both SO_x and particulate matter were produced; in 1966, for example, 14 million tons of SO_x were produced.(22) Coal-firing accounted for 13 million tons, oil accounted for 1 million tons, and gas accounted for 3,500 tons. Most of the SO_x is discharged to the atmosphere.

Coal-burning is the major contributor of both SO_x and particulate emissions in the steam-electric generating industry. The emission of SO_x is independent of the combustion system and may be calculated by using a factor of 38 pounds of SO_x per ton of coal for each percentage of sulfur content. Table D-34 indicates the hourly production of SO_x

for a range of heat rates for coal with 1- and 2-percent sulfur content.[a]

Of the three grades of residual fuel oil,[b] No. 6 (commonly called Bunker C) is the most often used to fire utility boilers. The emission of SO_x may be calculated by using the factor 158.8 pounds of SO_x[c] per 1000 gallons of oil for each percentage of sulfur.(22) Table D-34 also indicates the hourly production of SO_x for a range of heat rates for 1.38 and 2.76 percent sulfur content for oil. The hourly production of SO_x with 1.38 percent oil equals the hourly rate of coal at 1 percent; the hourly rate at a sulfur content of 2.76 is equivalent to the rate of coal with sulfur content of 2 percent. South American residual oil with an average sulfur content of 2.25 percent represents 61 percent of the utility oil consumed;(22) American oil with an average sulfur content of 1.76 percent represents 39 percent.

Emissions of SO_x from gas-fired boilers are well below the moderate standard adopted for this study.

The total production of particulates in 1966 amounted to over 21 million tons. Coal-burning accounted for 16.15 million tons, petroleum for 0.03 million tons, and natural gas for 0.02 million tons. However, substantial control of particulates is being practiced; the estimated emission to the atmosphere is 2.26 million tons--which is based on estimates of particulate control at 86 percent of coal consumed.(23)

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[a] Note that the hourly emissions for 1-percent sulfur coal represents the maximum allowable emissions under this study's stringent standard.

[b] ASTM subdivided residual oils into grades 4, 5, and 6.

[c] Includes SO_3.

Table D-34. SO_x UNCONTROLLED EMISSIONS FROM COAL- AND OIL-FIRED BOILERS BY SULFUR CONTENT AND HEAT RATE

Heat Rate (10^6 Btu/hr)	100	500	1,000	2,500	5,000	7,500	10,000
			(Pounds of SO_x/hr)				
1% Sulfur Coal 1.38% Sulfur Oil	146	730	1,460	3,650	7,300	10,950	14,600
2% Sulfur Coal 2.76% Sulfur Oil	392	1,460	2,920	7,300	14,600	21,900	29,200

The amount of particulates from coal, however, depends on the combustion system. Systems using pulverized coal in firing represent 90 percent of all systems currently in use in the industry; cyclone firing represents 10 percent.(24)

A general size distribution of particulates from pulverized coal firing units is shown in table D-35.(25) The extremely large percentage of small particles makes compliance with stringent standards possible with only highly efficient control equipment. For both the pulverized and cyclone units, the percentage of particulates that are smaller than 10 microns exceeds 30 percent. Table D-36 compares uncontrolled emissions with the New York standard, the stringent particulate standard of this study.

The emission of particulates from oil-fueled boilers is shown as a function of boiler size in table D-36.[a/] These emission rates satisfy the stringent particulate emission standards adopted for this study.

[a/] The emission factors used in derivation of the table D-36 are found in NAPCA Publication No. AP-51 op. cit., p. 53., reference (23).

Table D-35. SIZE DISTRIBUTION OF PARTICULATES EMITTED FROM PULVERIZED COAL-FIRED BOILERS

Particle size, micron	Percent, by weight
< 44	78.0
44-74	10.0
74-149	8.3
> 149	3.7

D.5.2 Alternative Emission Controls for Boilers

Of the five techniques that can be used to control particulate air pollution from stationary combustion sources, energy substitution and gas-cleaning are the two alternatives discussed in this study.[a/]

Gas-cleaning is presently the most common means of controlling particulate emissions from steam-generating sources.[b/] On cyclone and pulverized-coal firing units, high efficiency electrostatic precipitators are used to obtain optimum control. Initial attempts to control using high efficiency cylcone collectors for both the cyclone and pulverized units achieved efficiencies no higher than about 80 percent. Later the stricter legal pressures for gas-cleaning brought about the widespread use of electrostatic precipitators. The first generation of electrostatic precipitators provided efficiencies

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[a/] Department of HEW. Control Techniques for Particulate Air Pollutants; Preliminary Statement. National Air Pollution Control Administration Publication No. AP-51, 1968, pp. 3-15. The other control techniques mentioned are: energy conservation, good practice, and source shutdown.

[b/] See reference (24) for a history of control efficiency.

Table D-36. COMPARISON OF UNCONTROLLED PARTICULATE EMISSIONS WITH THE STRINGENT STANDARD

	Btu Rating, 10^6 Btu/hr							
	50	100	500	1000	2500	5000	7500	10,000
	Emission Rate, lb/hr							
Standard	23	40	150	260	580	1000	1420	1800
Coal-cyclone fired	40	80	400	800	2000	4000	6000	8000
Coal-pulverized coal system	348	697	3483	6967	17417	34167	52250	69667
Residual Oil - $\geq 100\times10^6$ Btu/hr	--	6.9	34.5	79	172.5	345	517.5	690
Residual Oil - $< 100\times10^6$ Btu/hr	7.9	--	--	--	--	--	--	--
Natural Gas - $\geq 100\times10^6$ Btu/hr	--	1.5	7.5	15	22.5	45	67.5	90
Natural Gas - $< 100\times10^6$ Btu/hr	0.9	--	--	--	--	--	--	--

of 90-95 percent.[a/] Later, precipitators used in series with high efficiency cyclones yielded overall removal efficiencies in excess of 99 percent. Now precipitators are available that provide collection up to 99 percent without using a cyclone. Therefore, this study assumes that high efficiency electrostatic precipitators are the preferred equipment on steam-electric boilers to remove particulate emissions when the control standards call for efficiencies between 80 and 99 percent.

Control of the emissions of SO_x can theoretically be achieved with several alternatives: substitution of natural gas for coal and oil, desulfurization of coal and oil, or the gasification of coal. However, these are extremely costly. Order of magnitude costs for these three alternatives are presented below. A fourth alternative, substitution of coal with low sulfur content for fuel with higher content, increases transportation costs from mine to plant and would thus add greatly to total fuel costs. In addition, the reserves of coal with low sulfur content may not be adequate.(26) For these reasons, the fourth alternative was not considered further. A fifth alternative, removal of SO_x from the effluent of boilers appears to be the most promising. Based on available knowledge, costs for this means of control are given below.

D.5.3 Cost of Controls

Essentially the same method was used to estimate costs in the steam-electric power generation industry that was used in the gray iron foundries. Data to describe the electric power plants and their boilers were taken from a publication of the Federal Power Commission.(27)

[a/] The first generation of precipitators may be thought of as those manufactured prior to 1960.

Data was included for 530 conventional fossil-fueled plants in the contiguous United States, Hawaii, and Puerto Rico; these accounted for 96 percent of the total net power generation in 1967. Small plants (under 25 megawatts capacity) and new plants reported during the last six months of 1967 were not included in Commission's reports.

The 1967 data on 301 plants with capacities of 100 megawatts or greater that were fueled by coal and/or oil included: location and capacity, quantities of coal and fuel oil burned, Btu content of fuel, number of boilers, and year of plant startup.

For this study, it was assumed that the generating capacity of each plant was provided by equal-sized boilers; this is to say that boiler capacity could be estimated by dividing the plant capacity by the number of boilers installed. The resulting distribution of boiler by capacity is shown in table D-37.

Data were also collected from 60 plants which, for the most part, were equipped with particulate collection systems. These data were the basis for estimating the annual as well as the investment costs for mechanical and electrostatic precipitator collection systems. These cost data (adjusted to 1967 price levels) were used in linear regression analyses to estimate unit costs for additional control systems.[a]

In the 301 steam-electric power plants considered, 1009 boilers burn some coal and 176 burn fuel oil but no coal. (These do not include plants operated by TVA.) An analysis was made to determine which plants were equipped with particulate control equipment. No

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[a] The data used represented controls installed at the time the plants surveyed were built. It was assumed that the cost difference is insignificant for controls installed at the time boilers are installed and for controls installed later.

Table D-37. AN ANALYSIS OF BOILERS IN STEAM-ELECTRIC POWER PLANTS BY SMSA'S(27)

Number and capacity of coal-burning boilers[a]			
Capacity rating,[b] megawatts	Inside SMSA's	Outside SMSA's	Total inside and outside SMSA's
	No. of boilers	No. of boilers	No. of boilers
0- 49.9	197	65	262
50- 99.9	230	107	337
100-149.9	101	75	176
150-199.9	44	43	87
200-249.9	39	45	84
250-299.9	12	8	20
300-349.9	14	7	21
350-399.9	5	4	9
400-449.9	0	2	2
450-499.9	2	0	2
500-549.9	0	0	0
550-599.9	3	2	5
600-649.9	3	0	3
650-699.9	0	1	1
700-749.9	0	0	0
Total	650	359	1009

a/ Boilers in plants operated by TVA were not included.

b/ Boiler capacity was estimated by dividing plant capacity by total boilers in the plant.

data was available for a direct estimate, but indirect estimates indicate that 85-90 percent of the power from coal is generated under emission control.

The analytical method used to amplify the indirect estimates was to apply a characteristic growth curve for the installation of emission control devices. This curve (see figure D-2), by installation year, yielded the percentage of boilers with control. The S-shaped growth curve starts in 1915 with the first known installation and grows to 100 percent in 1964; one plant was known to have installed a boiler without control in 1963. For correlation purposes, a curve representing the average size of boilers installed each year was plotted on figure D-2. To estimate the degree of control of each installation, data from Moore,(24) which gave the distribution of fly ash collection efficiency by year of installation, was used.

The overall results for the 1009 boilers estimate that 72 percent have installed systems and that the overall collection efficiency of the installations is 81 percent weighted by capacity. (See table D-38.) However, since newer and larger boilers are operated a larger percentage of the time, the collection efficiency of actual operations is expected to be several percentage points above 81 percent.

Because the hypothetical analysis (described above) produced results that agree with frequently quoted indirect estimates, the results were used to determine the number of boilers without controls and with controls that are less effective than both the moderate and the stringent standards required. Tables D-39 and D-40 present the results.[a/]

[a/] It was assumed that all plants which burned some coal during 1967, but that are now thought to be without pollution control systems, should be included in the estimate. This is to say that it was assumed that no boilers would be shut down.

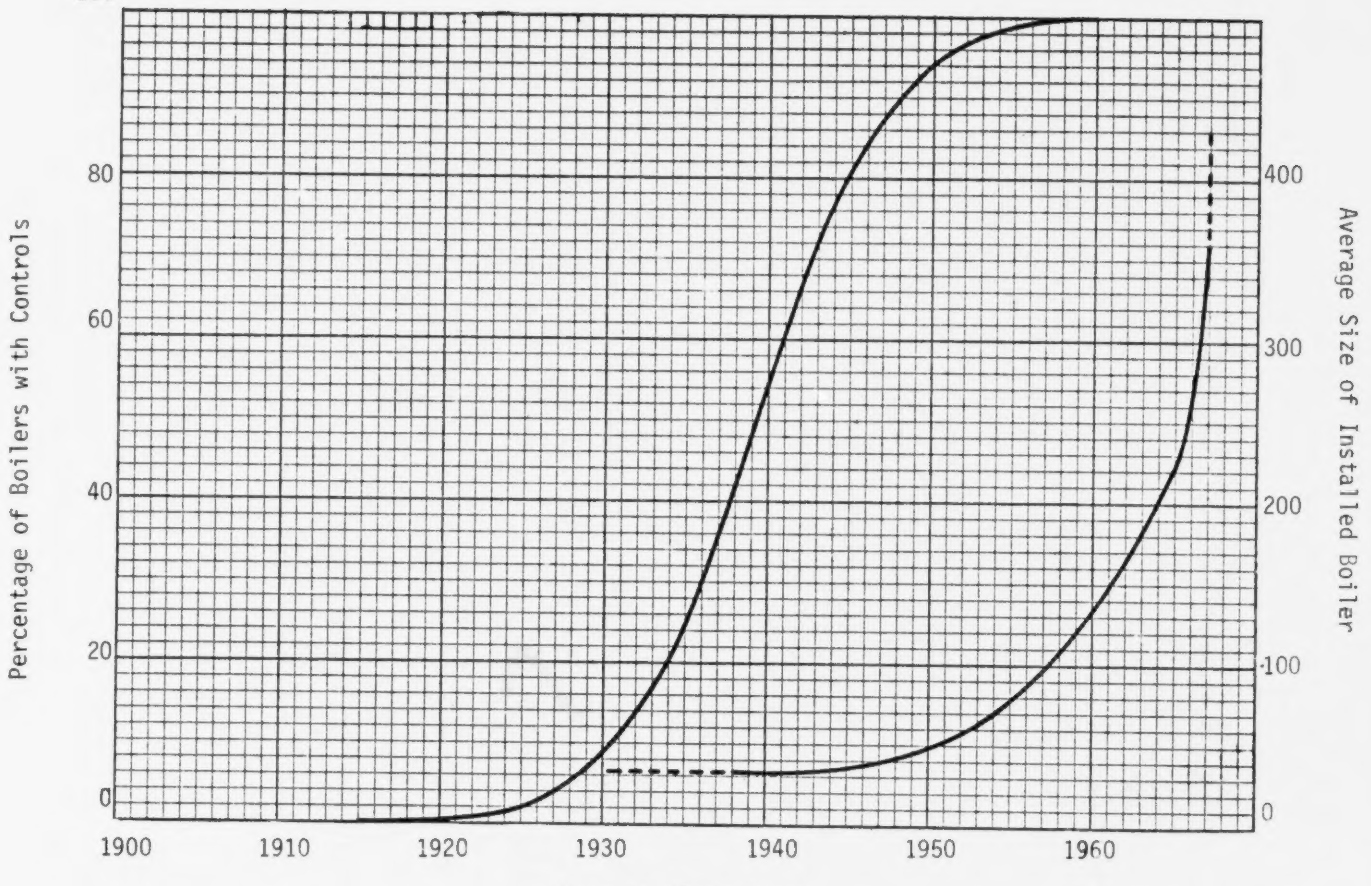

Figure D-2. Steam-electric boilers by year percentage installed with emission controls and average size of installed boilers.

Table D-38. EFFICIENCY OF EXISTING CONTROLS ON STEAM-ELECTRIC POWER BOILERS

Boiler capacity, megawatts	Total no. of boilers	No. with existing controls	Efficiency of existing controls* percent					
			20	40	70	80-90	90-95	95-99.5
0- 49.9	262	93	--	13	80	--	--	--
50- 99.9	337	225	3	--	66	45	61	50
100-149.9	176	176	--	--	55	12	26	83
150-199.9	87	86	--	--	16	--	7	63
200-249.9	84	84	--	--	10	--	--	74
250-299.9	20	20	--	--	2	--	--	18
300-349.9	21	21	--	--	--	--	--	21
350-399.9	9	9	--	--	--	--	--	9
400-449.9	2	2	--	--	--	--	--	2
450-499.9	2	2	--	--	--	--	--	2
500-549.9	0	0	--	--	--	--	--	0
550-599.9	5	5	--	--	--	--	--	5
600-649.9	3	3	--	--	--	--	--	3
650-699.9	1	1	--	--	--	--	--	1
700-749.9	--	--	--	--	--	--	--	--

* Estimated by growth pattern technique.

Table D-39. COST OF EQUIPMENT FOR CONTROLLING STEAM-ELECTRIC POWER BOILERS EMISSIONS--UNIFORM STANDARD

Boiler capacity, megawatts	Number of boilers burning pulverized coal			Initial investment for control equipment ($1000)	
	With control[a]	Needing control	Efficiency required %	Per boiler	Total for needed controls
25	0	236	94.7	$ 364.2	$ 85,951
75	100	203	95.8	506.0	102,718
125	98	60	96.0	636.7	38,202
175	63	15	96.1	768.9	11,534
225	67	9	96.2	902.4	8,122
275	16	2	96.3	1037.5	2,075

Investment cost - $248,602,000

Annual cost @ 0.1544 x Investment - $38,384,000

	Cyclone fired boilers[b]				
25	8	16	57.5	$ 76.8	$ 1,229
75	23	11	66.0	154.8	1,703

Investment cost - $2,932,000

Annual cost @ 0.2182 x Investment - $640,000

Total costs for both type boilers

Investment cost - $251,534,000

Annual cost - $39,024,000

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[a] Controls sufficient for stringent standards.

[b] Controls for cyclone fired boilers meet the requirements of both standards.

Table D-40. VARIABLE STANDARD COST OF EQUIPMENT FOR CONTROLLING STEAM-ELECTRIC POWER BOILER EMISSIONS

Boiler capacity, megawatts	Number of boilers burning pulverized coal				Initial investment for control equipment ($1000)	
	Total	With control*	Needing control	Efficiency required %	Per boiler	Total for needed controls
Inside SMSA						
25	177	0	177	94.7	364.2	64,463
75	206	68	138	95.8	506.0	69,828
125	90	56	34	96.0	636.7	21,648
175	40	32	8	96.1	768.9	6,151
225	35	32	3	96.2	902.4	2,707
275	11	10	1	96.3	1037.5	1,038
Outside SMSA						
25	59	0	59	89.4	201.9	11,912
75	97	32	65	91.6	389.2	25,298
125	68	42	26	92.0	511.4	13,296
175	38	31	7	92.2	622.7	4,359
225	41	35	6	92.4	741.5	4,449
275	7	6	1	92.6	859.0	859

Investment cost - $226,008,000

Annual cost @ 0.1544 x Investment - $34,896,000

Total costs adding in cyclone fired boilers (from table D-39)

Investment cost - $228,940,000

Annual cost - 35,536,000

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* Controls meeting applicable standards.

D.5.4 Control of Sulfur Oxides

Processes to eliminate sulfur oxides from the effluent of coal-fired utility boilers are still under development. At the present stage of knowledge, cost estimates have been made as shown in table D-41. The costs presented are considered best judgment of the cost of fitting the control scheme to an existing installation. It should be kept in mind by the reader that costs presented are order-of-magnitude estimates and that it is unlikely that all plants costed will actually be controlled in the future. At best, these costs are the upper limit of control cost for existing plants.

TABLE D-41. PROCESSES TO REMOVE SO_2 FROM BOILER EFFLUENT

Control scheme	Capital cost, $/kW	Annual cost, $/ton coal	Application
Product producing:			
H_2SO_4 recovery	25 - 35	1 - 2[d]	All boilers greater than 500 MW and less than 10 years of age. 13% of total capacity.
Sulfur recovery	15 - 30	1 - 2[d]	
Fuel substitution:			
Low sulfur coal[a]	negligible	1.50 - 3.00	11% of capacity less than 500 MW.
Gas[b]	negligible	1.50 - 3.00	
Coal cleaning[c]	negligible	0.50	20% of capacity less than 500 MW.
Throwaway:			
Wet limestone	9 - 12	1.50 - 3.00[e]	48% of capacity less than 500 MW.
Dry limestone	5 - 8	1.50 - 3.00[e]	31% of acpacity of boilers less than 200 MW which comprise 21% of capacity less than 500 MW.

[a] Assumed 10 x 10^6 tons of 1 percent S coal available.

[b] Assumed 20 percent increase in gas available to utilities at a premium.

[c] Assumed 17 percent of all utility coal cleanable to 1 percent S.

[d] Includes credit for sale of recovered product.

[e] Includes cost for disposal of collected material.

For purposes of the analysis only coal/oil plants meeting the following criteria were considered:

(1) Must burn less than 20% gas.

(2) Must be located east of the Mississippi River or in the States of Minnesota, Iowa, and Missouri.

(3) Must have installed a new boiler since 1939.

(4) Must have a capacity of 100 MW or greater.

The total installed capacity of the plants considered is 130,598 MW. The analysis does include TVA plants.

Table D-42 presents the total cost of applying the control schemes to presently existing plants. It was assumed the control schemes would also include provision for particulate control.

TABLE D-42. STEAM-ELECTRIC BOILERS PARTICULATE AND SO_2 CONTROL COSTS

Initial Investment (millions of dollars)	Annual Costs (millions of dollars)
953 - 1403	319 - 616

D.5.5 Economic Effect

The steam-electric power generating industry is a public utility comprised of both publicly and privately owned electric power systems and subject to regulation. Economic features of public utilities set them apart from other industries.(28).

Two sets of criteria provide the basis for regulating public utilities. The first, the legal basis, is concerned with protecting the public and imposing legal obligations and restrictions. The second set is the economic bases for regulation; there are three economic criteria in the set.

D.5.6 Consumer-Producer Relationship

Public utilities are natural monopolies as far as their economic structure is concerned; the relative share of fixed and specialized capital is higher than in other industries, and the service is supplied directly to the consumer. A natural monopoly, which is a necessity and for which there is no ready substitute, has a unique consumer-producer relationship that requires regulation.(28)

D.5.7 Pricing Problems

Whether the public utility is publicly or privately owned, the problems of pricing are the same: "... they are that of isolated and insulated monopoly ... Regulation is the substitute for the arbitrament of the market; the reconciliation of the interests of producer and consumer, which competition in the market achieves, is the task of regulation."(28)

D.5.8 Control of Competition

In the case of public utilities, control of competition between potential suppliers avoids duplication of resource expenditures and prevents minor practices in the market that limit the quality of service.

The demand for electric power is highly inelastic. An unregulated monopoly could deliver its output at a price greater than the marginal cost of production, but a regulated monopoly is subjected to pricing policies designed to equate price to short-run marginal cost, allowing a fair rate of return on investment.

Therefore, considering the well-defined market that is supplied by a public utility and the monopolistic characteristics of the industry, it would appear that any increase in costs imposed on the steam-electric industry can be readily absorbed into its pricing structure. If, in fact, the industry is to lend itself to larger and more comprehensive electric supply systems, the cost structure may be subject to economies of scale so that part of the costs of emission control may be absorbed in the existing rate base.

The general pattern of energy consumption for the electric utilities in industry as a whole has shown impressive growth. Over the period 1950 to 1965, fuel input requirements more than doubled. The period 1965 to 1980 is expected to show increases of more than three times the 1950 fuel level demand;(29) however, the industry will not ordinarily be subject to limited quantities of fuel supply in the foreseeable future.(30)

The composition of fuel demands has also changed and is expected to change even more in the near future. Electric utilities now comprise the largest single market for coal, accounting for over one-half of the total consumption. Continued expansion of the industry will have marked effects on the structure of the coal industry. Additionally, if air pollution regulations impose restrictions on the sulfur content of fuel, severe pressures on low sulfur content fuel will result in upward price pressure and increased pressure to consider means of reducing sulfur content of coal. Because of the dominant position of the electric power market for coal suppliers, additional costs of reducing the sulfur content of coal may be imposed, to some extent, on the suppliers. Thus, a potential impact is poised for coal suppliers.

The unique position of the steam-electric power industry has made possible the extensive use of emission control in the past. For a pulverized coal-fired boiler of 125 megawatts, the annual costs of particulate control are less than 0.1 mil per kWh or about 2 percent additional production expense. Total production costs to the industry per kWh have continued to decline over several years although the trend may be ending. Hence, some additional nonproductive costs can be absorbed without rate increases; the balance can be transmitted to a wide customer base or transferred to coal suppliers.

In the past, the steam-electric industry has demonstrated its willingness to comply with emission standards. If this can be used as an indicator for the future, the industry can be expected to be the first to adopt proven SO_x control practices, and it is reasonable to predict that costs will be passed on to consumers through power rate adjustments.

The removal of sulfur from coal or SO_x from the effluent of utility boilers appears to be the most cost effective solution to the SO_x problem. Reduction in coal consumption that would occur with other alternatives would present additional economic difficulties to railroads and coal mines.

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APPENDIX E

COST OF COMPLIANCE ESTIMATES: MODEL PLANT PROCEDURE

APPENDIX E

COST OF COMPLIANCE ESTIMATES:
Model Plant Procedure

E.1 MODEL PLANT COST ESTIMATING PROCEDURE

The cost estimating procedure is divided into three parts which include: (a) selection of model plant or plants to represent the industry, (b) selection of control system and control system costs, and (c) determination of industry control cost estimate and evaluation of economic impact. This procedure is illustrated in figure E-1.

Step 1: Selection of a Model Plant to Represent the Industry.

An average size plant (i.e., average by production capacity) is used as the basic industry model. This technique is valid when the industry plant size frequency distribution is symmetrical or assumed symmetrical about the mean. For industries where a distinct bimodal plant size distribution exists, two model plants are determined and impact indicators calculated for each plant. Portions of the total industry output is then allocated to each model plant and the gross industry control cost is determined.

When substantial quantities of the entire industry output are produced by more than one process type, model plant or plants are determined for each process type. An example is the sulfuric acid industry, where both the chamber and contact processes significantly contribute to the total industry output.

Only the major polluting processes typically found in such plants are specified once the model plant is determined. Those that must be controlled are then characterized as model processes, using the method previously described for determining the model plant size.

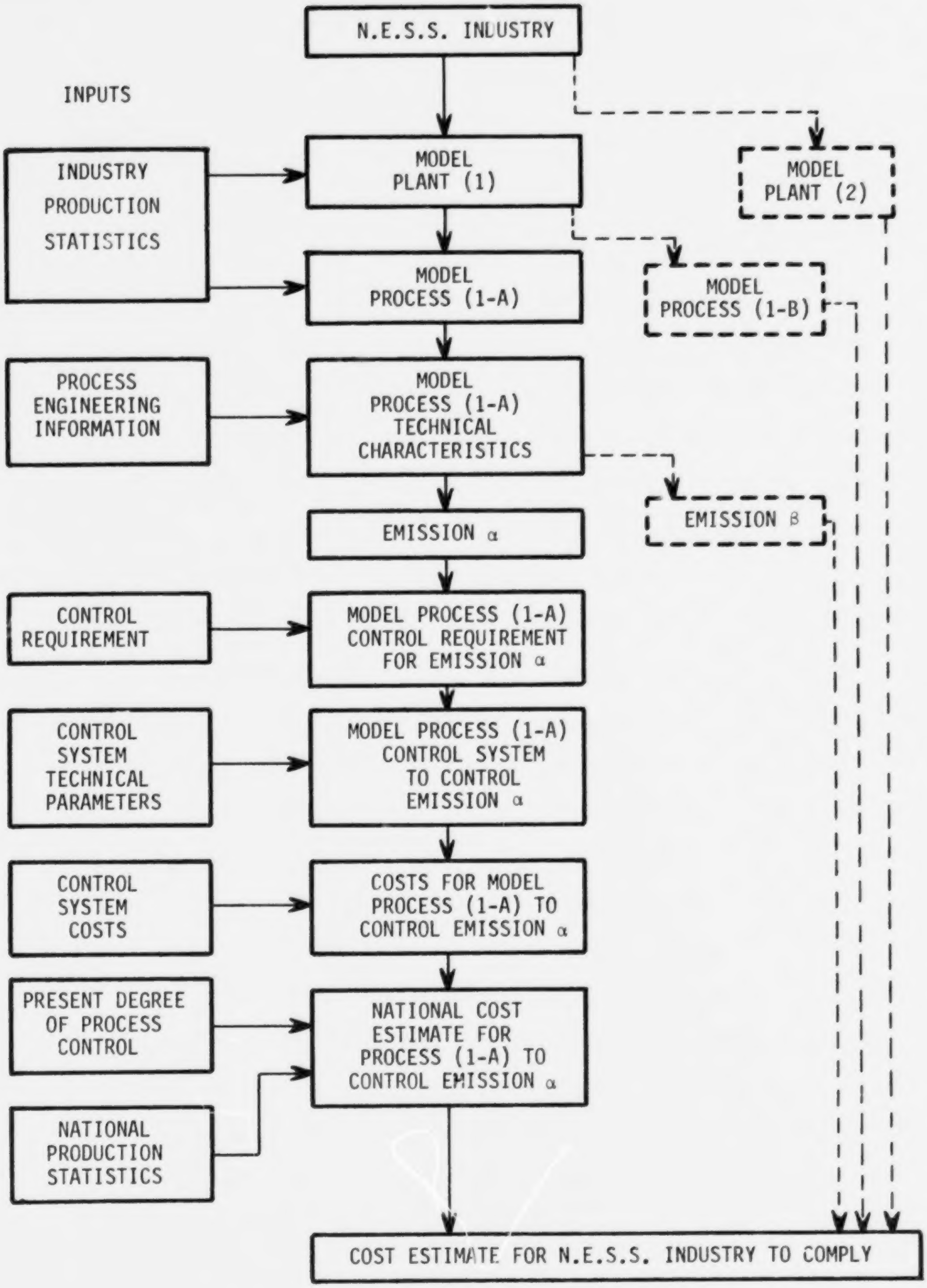
N.E.S.S. INDUSTRY
INPUTS
INDUSTRY PRODUCTION STATISTICS
MODEL PLANT (1)
MODEL PLANT (2)
MODEL PROCESS (1-A)
MODEL PROCESS (1-B)
PROCESS ENGINEERING INFORMATION
MODEL PROCESS (1-A) TECHNICAL CHARACTERISTICS
EMISSION α
EMISSION β
CONTROL REQUIREMENT
MODEL PROCESS (1-A) CONTROL REQUIREMENT FOR EMISSION α
CONTROL SYSTEM TECHNICAL PARAMETERS
MODEL PROCESS (1-A) CONTROL SYSTEM TO CONTROL EMISSION α
CONTROL SYSTEM COSTS
COSTS FOR MODEL PROCESS (1-A) TO CONTROL EMISSION α
PRESENT DEGREE OF PROCESS CONTROL
NATIONAL PRODUCTION STATISTICS
NATIONAL COST ESTIMATE FOR PROCESS (1-A) TO CONTROL EMISSION α
COST ESTIMATE FOR N.E.S.S. INDUSTRY TO COMPLY

Fig. E-1. Flow chart of cost estimating procedure.

The model plant is described by the following production and engineering characteristics:

a. Plant size
b. Type process(es)
c. Process size(s)
d. Process(es) annual output
e. Process(es) gas volume
f. Process(es) gas stream temperature
g. Process(es) emission type
h. Special emission characteristics
i. Process(es) uncontrolled emission rate
j. Process uncontrolled annual emission
k. Annual hours of operation

Step 2: Selection of Control System and Control System Costs.

The 15 industries examined in this chapter include a wide variety of emission types. Because some of these industries have substantial emissions other than particulates and sulfur oxides (i.e., other gaseous compounds and odors), cost estimates will be made for the control of each emission type which is believed to be detrimental to the environment (including carbon monoxide, hydrogen sulfide, nitrogen fluoride, hydrocarbons and odors) or is considered a potential local nuisance.

The degree of control required for each of the 15 industries is defined as "technically feasible and economically reasonable." In general, the degree of control required should result from a technology that has been tried and proven. Also this technology should not be so costly that a significant number of the plants within the industry would choose to shut down rather than control emissions.

The control system designated for any model process will be described by its various components. The significant components of each control system are basic equipment, gas-conditioning equipment, utilities, and method of captured-pollutant disposal. The total control system is then characterized by its size, control efficiency, and cost.

Two important control cost categories are investment and annual cost. Components of these categories are listed in tables C-1 and C-3 of appendix C. The expected cost variation results from the factors listed in table C-2.

No cost credit is given to plants operating inadequate systems that cannot be upgraded. Full credit is given plants that are now operating systems that are considered adequate.

Step 3: Determination of Industry Control Cost Estimate and Evaluation of Impact.

Once the high and low costs of the selected control systems are determined, the estimates are divided by the annual output of the model plant to determine an indicator of impact. This indicator represents the impact of the cost on the model plant, and also represents the average impact for the industry as a whole. Thus, the indicators (i.e., high and low) are applied to the total industry output to estimate the gross cost of control.

The concept of using model plants should be investigated more fully to verify its applicability to varying situations. In general, the concept, by using the average size plant, avoids economies or dis-economies of scale. When applied to the cost of air pollution control, it states that the cost of emission control per unit of production decreases as the size of the plant increases. Thus, using the model plant as a reference point, firms smaller than the model plant are, in general, expected to face a greater impact (i.e., control cost per unit of production) than the model plant, and plants larger than the model plant a lesser impact. This concept and the assumption that the model plant is average in size with a symmetrical distribution about the mean, implies that the impact for the model plant is the average for the industry. Thus, it can be used in arriving at gross estimates.

To illustrate the effect of the economies of scale on impact, an example, using the gray iron foundry industry, is presented in table E-1. The table shows the expected impact on three model gray iron foundries controlled by fabric filter (baghouse) systems. Model plant B operates a cupola melting at 10 tons per hour, an average for the industry. Model plants A and C operate cupolas that melt at 5 and 25 tons per hour, respectively. Notice the significant deviation of control cost per ton of castings for the plants not representative of the industry average production rate.

Table E-1. EXPECTED IMPACT VARIATION RELATIVE TO FOUNDRY SIZE

Model Plant	Cupola Melt Rate, ton/hr	Control System Investment*, $	Annual Control Cost*, $/yr	Expect Annual Production of Castings, ton/year	Control Investment Per Ton of Castings, $/ton	Annual Control Cost Per Ton of Castings, $/ton
A	5	80,000	25,000	3,900	20.51	6.41
B	10	128,000	40,000	10,500	12.19	3.81
C	25	270,000	81,000	30,000	9.00	2.70

* Fabric Filter System assumed for this example; efficiency = 99+%.

E.2 INDUSTRIAL CATEGORIES

E.2.1 Carbon Black[1,2,3]

E.2.1.1 Industry Production

As stated in chapter 2 of the NESS report, production of carbon black from the 3 carbon black manufacturing processes in 1967 was 2,483,840 tons. Annual capacity in 1967 was 1,533,000 tons. The average annual value of shipments for 1966-67 was $181,233,000. Price per pound for carbon black varied from $0.055 to $1.830 with an average price of about $0.073 per pound.

E.2.1.2 Industry Emissions

Particulate emissions from the carbon black industry are estimated to be 103,000 tons per year. About 97 percent of this total is estimated to be emitted in the channel black process, which accounts for only about 6 percent of the total carbon black production. Emissions of carbon monoxide, the other significant pollutant, are estimated to be 285,000 tons per year.

E.2.1.3 Degree of Control of Emissions

The three processes for carbon black production as outlined in chapter 2 of the main report, are the channel process, the thermal process, and the furnace process (gas furnace or oil furnace). None of the six plants which produce channel black control their emissions because appropriate technology does not exist. All 24 of the plants which use the furnace process control particulate emissions with an efficiency of 95-99+ percent. None of the 24 controls carbon monoxide emissions. The three plants employing the thermal process have no emissions because the thermal process is a closed system.

E.2.1.4 Model Plant

The model plant used in estimating cost of control for the carbon black industry employs the furnace process. Since emissions from channel process plants cannot be controlled, no cost estimate can be made for these plants. No cost estimates are necessary for thermal process plants, since the process inherently has no emissions.

Cost estimates will be made only for control of carbon monoxide in the furnace process. The plants have an assortment of cyclones, baghouses, and other equipment which controls particulate emissions. However, this equipment must be considered process equipment and not air pollution control equipment, since it is economically advantageous for the industry to control with baghouses. There can be particulate emissions in the furnace black plant from leaks, spillage, and cleaning operations. Control of these emissions, however, is a function of good housekeeping and maintenance, and the estimation of costs incurred from these practices is beyond the scope of this study.

Characteristics

The characteristics of the model carbon black plant are:

Type process - - - - - - - - - - - Furnace black
Annual output - - - - - - - - - - - 48,000 tons
Gas volume- - - - - - - - - - - - - 75,000 acfm
Gas temperature - - - - - - - - - - 400°F
Emission type - - - - - - - - - - - 5-11% CO in gas stream
Annual hours of operation - - - - 2,000
Annual emissions with no control - - - - - - - - - - - - - 13,440 T of CO
Average sales price per ton - - - $146

Control System

The control system for eliminating carbon monoxide is a flare-type afterburner. With an assumed efficiency of 95 percent, the CO emissions from the model plant will be reduced from 13,440 T/yr to 667 T/yr. The estimated control costs are:

	Low	High
Investment Cost	$81,000	$462,000
Annualized Cost	$16,900	$ 72,800

Impact

The 48,000 T/yr of furnace black produced in the model plant will yield about $7,008,000/yr in sales. The impact on the model plant from controlling CO emissions is:

	Low	High
Annual Control Cost/Ton CO Destroyed ($/T)	$1.32	$5.70
Annual Control Cost/Ton Carbon Black Produced ($/T)	$0.35	$1.52
Annual Control Cost as a Percent of Sales (%)	0.24%	1.04%

E.2.1.5 Estimated Industry Control Costs

By using the model plant costs, control costs for the entire furnace black industry can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost	$1.70	$9.70
Annualized Cost	$0.36	$1.53

E.2.2 Cement(4,5)

E.2.2.1 Industry Production

Annual capacity of cement plants in 1968 was about 95,000,000 tons. The average annual production for the preceding five years was about 74,000,000 tons. Value of shipments for 1968 is estimated to be $1,200,000,000. There are 116 plants producing cement by the wet process and 62 producing cement by the dry process.

E.2.2.2 Industry Emissions

Particulate emissions from cement plants are estimated to be 790,000 T/yr. The largest source of these emissions is the kiln.

E.2.2.3 Degree of Control of Emissions

It is estimated that 99 percent of the plants control emissions to some degree. The estimated control efficiencies of control equipment on the kilns of those plants controlling are:

% of Total No. of Plants	Control Efficiency of Kiln Emissions (%)
20	99.5
10	97 - 99.5
10	95 - 97
10	93 - 95
10	90 - 93
40	75 - 90

The estimated control efficiencies of control equipment on raw material dryers in dry process plants are:

% of Total No. of Plants	Control Efficiency on Dryer (%)
50	96 - 98
50	90 - 96

No estimates are available for the control efficiencies of control equipment on the clinker grinding part of the process.

E.2.2.4 Model Plant

Two model plants will be used to estimate the cost of control for the industry. One will employ the wet process, and the other the dry process. Control costs will be estimated only for control on the kiln and clinker grinding operations in the wet process and for control on the raw material drying, kiln, and clinker grinding operations in the dry process.

Characteristics

The two model plants will have the following characteristics:

	Wet Process	Dry Process
Annual Output	388,000 tons	388,000 tons
Exit Gas Volume		
Kiln	300,000 acfm	300,000 acfm
Clinker grinding	15,000 acfm	15,000 acfm
Raw material drying	-	150,000 acfm
Gas Temperature		
Kiln	375°F	500°F
Clinker grinding	Ambient +	Ambient +
Raw material drying	-	150°F

	Wet Process (cont.)	Dry Process (cont.)
Emission Type (All Sources)	Particulates	Particulates
Annual Hours of Operation (All Operations)	7200	7200
Annual Emissions With No Controls		
Kiln	39,000 T/yr	44,000 T/yr
Clinker grinding	12,000 T/yr	12,000 T/yr
Raw material drying	-	63,000 T/yr
Total	51,000 T/yr	119,000 T/yr
Average Sales price per ton	$17.11	$17.11

Control System

Emissions from the kiln on both the wet and dry process model plants are controlled by a baghouse equipped with glass fiber bags and automatic cleaning. Emissions from the clinker grinders in both model plants and from the raw material dryer in the dry process model plant are controlled by a baghouse equipped with cotton bags. All baghouses should have an efficiency of about 99.5 percent in controlling emissions.

The estimated investment and annualized control costs for the model plants are:

Wet Process

	Low	High
Investment Cost	$371,000	$506,000
Annualized Cost	$ 85,800	$101,800

Dry Process

	Low	High
Investment Cost	$446,000	$606,000
Annualized Cost	$113,100	$131,300

In calculating the control costs the fact that capturing some of the emissions in the processes is economically beneficial was not considered. It was stated in chapter 2 of the NESS report that recovery of dust usually provides an economic return up to about 90 percent control of the kiln emission. Analysis of the variables involved to determine how much of the control costs incurred by the model plant is actually cancelled by benefits derived from material recovered is beyond the scope of this study.

With the above control systems on the model plants, emissions should be reduced to the outputs listed below:

	Emissions (T/yr)	
Emission Source	Wet Process	Dry Process
Kiln	195	220
Clinker grinder	60	60
Raw material drying	-	315
Total	255	595

Impact

The 388,000 T/yr of cement produced in each model plant will yield about $6,638,700/yr in sales. The impact on the model plant from controlling emissions is:

	Wet Process		Dry Process	
	Low	High	Low	High
Annualized Control Cost/Ton Particulates Collected ($/T)	$1.69	$2.01	$0.96	$1.11
Annualized Control Cost/Ton Cement Produced ($/T)	$0.22	$0.26	$0.29	$0.34
Annualized Control Cost as a Percent of Sales (%)	1.29%	1.53%	1.70%	1.98%

E.2.2.5 Estimated Industry Control Costs

By using the model plant calculations, control costs for the entire industry can be estimated as:

WET PROCESS

	Investment Cost in Millions of Dollars	
	Low	High
Kiln Control System		
Already Installed	$16.7	$22.7
Required	25.1	34.1
Total	$41.8	$56.8
Clinker Grinder Control System	$ 1.3	$ 1.9
Total	$43.1	$58.7

Annualized Cost

Low	High
$10.0	$11.8

DRY PROCESS

	Investment Cost in Millions of Dollars	
	Low	High
Kiln Control System		
Already Installed	$10.7	$14.5
Required	16.0	21.8
Total	$26.7	$36.3
Clinker Grinder Control System	$ 0.8	$ 1.2
Raw Material Dryer Control System		
Already Installed	2.2	3.0
Required	3.3	4.4
Total	$ 5.5	$ 7.4
TOTAL	$33.3	$44.9

Annualized Cost	
Low	High
$8.4	$9.7

The cost data labeled "Already Installed" and "Required" relative to the kiln control system were calculated for both the wet and dry process using the following information:

% of Total No. of Plants	Control Efficiency of Kiln Emissions(%)	Required Investment Cost as % of a New Baghouse (%)	Investment Credit as % of a New Baghouse (%)
20	99.5	0	100
10	97 - 99.5	20	80
10	95 - 97	40	60
10	93 - 95	60	40
10	90 - 93	80	20
40	75 - 90	100	0

An example will serve to clarify the use of the above table. It is estimated that 10 percent of the plants control kiln emissions in the 97-99.5 percent range. If a 99.5 percent emission standard was imposed, the plants would probably upgrade the systems they have instead of installing new baghouses. The estimated cost of upgrading, as shown in the table, is 20 percent of a new baghouse. Thus, for 10 percent of the plants the "Required" investment cost will be 20 percent of a new baghouse, and the "Already Installed" investment cost for 10 percent of the plants will be 80 percent of the cost of a new baghouse.

The same procedure was used in developing the cost data labeled "Already Installed" and "Required" under the heading "Raw Material Dryer Control System" (on the preceding page).

The following information was used in these calculations:

% of Total No. of Plants	Control Efficiency on Dryer Emissions (%)	Required Investment Cost as % of a New Baghouse (%)	Investment Credit as % of a New Baghouse
50	96-98	40	60
50	90-96	80	20

No attempt was made to divide costs for the clinker grinding control systems into "Already Installed" and "Required" categories because no information was available on the degree of control in the industry.

Annualized costs were calculated by assuming that all plants used baghouses for control. This assumption and the others made in this section are very broad, but are based on the best information available.

By combining the costs for the wet and dry process plants, control cost estimates for the entire cement industry can be made as:

	Millions of Dollars	
	Low	High
Investment Cost	$76.0	$103.6
Annualized Cost	$18.3	$ 21.5

E.2.3 Coal Cleaning(6-12,56)

E.2.3.1 Industry Production

There were 552,626,000 tons of bituminous coal produced in 1967. Of this total, 349,402,000 tons were cleaned in 667 plants. During the period of 1963-67, an annual average of 324,389,800 tons of coal was cleaned. Of this latter total, 72,680,000 tons were produced in plants employing the thermal drying process, and 22,438,400 tons were produced in plants employing the pneumatic cleaning process. The added value resulting from cleaning ranges up to $0.50/ton for an average of about $0.40/ton.

E.2.3.2 Industry Emissions

Emissions from coal cleaning plants are due to handling, cleaning, and drying operations. The principal emission sources are thermal dryers and pneumatic cleaners. Two types of thermal driers are employed: fluidized bed and flash. In the former, hot flue gases are passed up through a moving bed of wet coal. The size range of the coal and the hot-air velocity are the major factors determining the type and extent of emissions. In the flash evaporator, normally used for smaller sizes, the wet coal is dropped down a tube, through which hot flue gases are ascending.

An estimate for thermal-drying process emissions is 610,000 tons/yr of particulates, and for the pneumatic process emissions are estimated at 40,000 tons/yr of particulates.

E.2.3.3 Degree of Control of Emissions

It is estimated that 50 percent of coal cleaning plants using thermal driers control emissions to an average control efficiency of 85 percent. Of the coal cleaning plants using pneumatic cleaners, most, if not all, have cyclones. Cyclones, however, are not considered adequate control, and therefore, the number effectively controlling is essentially zero.

E.2.3.4 Model Plant

Two model plants will be used for estimating control costs. One will employ the thermal drying process, and the other will employ the pneumatic cleaning process.

Characteristics

The two model plants will have the following characteristics:

	Thermal Drying Process	Pneumatic Cleaning Process
Annual output	570,000 tons	223,000 tons
Production rate	156 T/hr	62 T/hr
Gas volume	85,000 acfm	25,000 acfm
Gas temperature	140°F	Ambient
Emission type	particulates	particulates
Annual emissions with no control	3,400 tons	386 tons
Annual hours of operation	3,600	3,600
Average value added	$0.40/T	$0.40/T

Control System

The control system for the model plant using the thermal drying process will be a cyclone followed by a venturi scrubber. With an estimated efficiency of 98 percent this system will reduce emissions from 3,400 T/yr to 68 T/yr. Estimated costs of the control system are:

	Low	High
Investment Cost	$53,000	$148.000
Annualized Cost	$20,200	$ 61,800

The control system for the model plant using the pneumatic cleaning process will be a baghouse. Although a cyclone will normally precede the baghouse, the cyclone must be considered process equipment and not air pollution control equipment, since the fine coal it collects is returned to be part of the product. With an estimated efficiency of 99.5 percent, the baghouse will reduce emissions from 386 T/yr to 2 T/yr. Estimated costs of the control system are:

	Low	High
Investment Cost	$16,000	$31,000
Annualized Cost	$ 3,600	$ 5,300

No attempt is made here to credit the value, if any, of recovered material in estimating control costs.

Impact

Value added by the cleaning in the thermal drying process model plant is $228,000/yr. Value added by cleaning in the pneumatic cleaning process model plant is $89,200/yr. The impact on the model plants from controlling emissions is:

	Thermal Drying Process		Pneumatic Cleaning Process	
	Low	High	Low	High
Annualized Control Cost/ Ton Particulates Collected ($/T)	$6.1	$18.5	$9.38	$13.80
Annualized Control Cost/ Ton Coal Cleaned ($/T)	$0.035	$0.108	$0.016	$0.024
Annualized Control Cost as a Percent of Value Added (%)	8.86%	27.10%	4.03%	5.94%

E.2.3.5 Estimated Industry Control Costs

By using the model plant costs, control costs for all plants employing the thermal drying process or the pneumatic cleaning process can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost		
Thermal Drying	$7.0	$19.5
Pneumatic Cleaning	1.6	3.1
Total	$8.6	$22.6
Annualized Cost		
Thermal Drying	$2.7	$ 8.2
Pneumatic Cleaning	0.4	0.5
Total	$3.1	$ 8.7

Plants employing these two processes account for only about 30 percent of the total coal cleaned, and therefore the industry cost estimates should not be considered as total industry costs. Estimates of control costs from other cleaning operations could not be made because of insufficient information.

Also because of insufficient information, no attempt has been made to apportion the costs to those for systems presently installed and those for required systems. The costs presented are simply the total costs of control for the plants employing the two processes.

E.2.4 Coke (By-Product)

E.2.4.1 Industry Production

Production of coke from by-product coke ovens amounted to 62,828,000 tons in 1968. Production has been nearly constant for the past five years. Estimated value of coke produced in 1968 is $1,252,630,000.

E.2.4.2 Industry Emissions

Four aspects of the coke process may be identified as major contributors to air pollution: (a) coal charging, (b) oven pushing, (c) coke quenching, and (d) combustion of coke oven gas.

Pollutants emitted during coal charging include carbonaceous smoke, tar mist, dust, and organic gases. Fine particulates and smoke are emitted during coke oven pushing. Coke quenching results in emission of particulate matter. Combustion of coke oven gas results in a release of sulfur dioxide as a result of burning hydrogen sulfide. Emissions from this industry are estimated to be 94,000 T/yr particulates, 600,000 T/yr sulfur dioxide, and 1,500,000 T/yr hydrocarbons.

E.2.4.3 Degree of Control of Emissions

Satisfactory control of emissions from coal charging is not technically feasible at this time. The problem lies in the present mechanism for introducing coal into the ovens.(13) During the heating of the coal, negative pressure removes gases, mists, and dusts through ascension pipes manifolded to a collection main. When the charging ports are opened, the negative pressure is lost and emissions unavoidably escape into the atmosphere due to the violent reaction following the dumping of damp coal into the hot ovens. Although a satisfactory method to control these emissions does not exist, use of steam jets in the raw-gas ascension pipes does help to reduce emissions. It is estimated that perhaps 50 percent of the plants reduce the emissions during the coal charge.(15) Because feasible control technology does not exist, it is assumed that no plants control emissions from coke oven pushing.

It is estimated that 10 percent of the plants control emissions from the quench tower.(14) The control efficiency of those controlling is 85 percent.(14) Only 10 percent of the plants are estimated to control SO_2 from combustion of coke oven gas.(14) Their control systems, which convert H_2S to elemental sulfur, can be assumed to reduce the sulfur emissions by 90 percent.(14)

E.2.4.4 Model Plant Characteristics (14)

The model plant to be used in making cost estimates has the following characteristics:

Type process	Coke (By-Product Oven)
Annual production	980,000 tons
Production rate	2,800 T/day
Gas volume (coke gas combustion)	30,000 cfm
Gas temperature (coke gas combustion)	ambient (70°F)
Emission type	
coal charging	smoke, dust, organic gases, tar mists
quench tower	coke dust
combustion unit (coke gas)	sulfur dioxide
Annual hours of operations	8,400

Annual emissions without control	
coal charging	700 T/yr particulates
quench tower	230 T/yr particulates
combustion unit	7,850 T/yr SO_2
Average price per ton coke	$20.00

Control System

The control system for the model plant includes the following components:

(a) steam nozzles in ascension pipes;

(b) baffle arrangement plus spray nozzles for installation within top of quench tower;(15)

(c) 10 ton per day elemental sulfur recovery.(16)

The steam nozzles in the pipes will burn much of the organic matter during the charging operations. No estimate of overall control efficiency of particulates can be accurately made. The reduction in gaseous sulfur pollutants is estimated at 90 percent.

Control costs of the described system for the model plant are:

	Low	High
Investment Cost	$175,000	$345,000
Annualized Cost (excluding product recovery)	$ 37,300	$ 60,000

Costs for control of particulates and sulfur dioxide can be categorized independently as:

Sulfur Recovery	Low	High
Investment Cost	$150,000	$250,000
Annualized Cost	$ 34,000	$ 47,300
Particulate Reduction		
Investment Cost	$25,000	$95,000
Annualized Cost	$ 3,300	$12,700

Eighty percent of the particulate reduction costs above is assigned to the coal charging operation.

Impact

The 980,000 tons of coke produced per year will yield $19,600,000 in sales. The impact of reducing emissions in the model plant is:

	Low	High
Annualized Control Cost/Ton Particulate Removed ($/T)	$3.94	$15.20
Annualized Control Cost/Ton Sulfur Dioxide Removed ($/T)	$4.81	$ 6.69
Annualized Control Cost/Ton Coke ($/T)	$0.04	$ 0.06
Annualized Control Cost as a Percent of Sales (%)	0.2%	0.3%

E.2.4.5 Estimated Industry Control Costs

By using the model plant control costs, incremental costs for the entire industry can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost	$9.8	$18.3
Annualized Cost	$2.1	$ 3.3

In deriving these estimates, it was assumed that the following number of plants would be required to control:

Control	Plants
Coal charging	33
Quench tower	59
Sulfur removal	59

No estimate was made of the amount the industry has spent on controls up to the present time.

E.2.5 Cotton Ginning(5,17-20)

E.2.5.1 Industry Production

Production of bales from cotton gins averages about 11,000,000 bales/yr. As stated in chapter 2 of the NESS report, production in 1968 amounted to about 10,830,564 bales. Production has been decreasing since

1964. Average price of cotton has varied over the period 1964-1968 from $0.21/lb to $0.33/lb. Assuming an average of about $0.27/lb, value of shipments in 1968 is estimated to be $1,460,000,000. An estimate of annual capacity of the gins is not available.

E.2.5.2 Industry Emissions

As stated in chapter 2 of the NESS report, particulates in the form of lint fly, dust, leaf particles, burs, sticks, stems, and motes are the primary emissions. Industry emissions are estimated to be about 30,000 T/yr.

E.2.5.3 Degree of Control of Emissions

Good information on the degree of control in the industry is not available. However, it is estimated that about 70% of the 4,448 gins control to some degree. Estimates of their control efficiencies are:

% of Total No. of Gins Controlling	Control Efficiency (%)
5	>90
35	50-90
60	<50

E.2.5.4 Model Plant

Characteristics

The model plant to be used in making cost estimates has the following characteristics:

Type process - - - - - - - - - - - - - - - - - Cotton Gin
Annual production - - - - - - - - - - - - - 2,500 bales
Production rate - - - - - - - - - - - - - - 5 bales/hr
Exit gas volume
  Suction line - - - - - - - - - - - - - - - - 9,000 acfm
  Burr line - - - - - - - - - - - - - - - - - 5,000 acfm
  Incline cleaner line - - - - - - - - - - - 6,500 acfm
  Lint cleaner line - - - - - - - - - - - - 2,500 acfm
  Overflow line - - - - - - - - - - - - - - 4,000 acfm
  Condenser exhaust - - - - - - - - - - - - 6,000 acfm
Exit gas temperature (all streams) - - - - Ambient

1964. Average price of cotton has varied over the period 1964-1968 from \$0.21/lb to \$0.33/lb. Assuming an average of about \$0.27/lb, value of shipments in 1968 is estimated to be \$1,460,000,000. An estimate of annual capacity of the gins is not available.

E.2.5.2 Industry Emissions

As stated in chapter 2 of the NESS report, particulates in the form of lint fly, dust, leaf particles, burs, sticks, stems, and motes are the primary emissions. Industry emissions are estimated to be about 30,000 T/yr.

E.2.5.3 Degree of Control of Emissions

Good information on the degree of control in the industry is not available. However, it is estimated that about 70% of the 4,448 gins control to some degree. Estimates of their control efficiencies are:

% of Total No. of Gins Controlling	Control Efficiency (%)
5	>90
35	50-90
60	<50

E.2.5.4 Model Plant

Characteristics

The model plant to be used in making cost estimates has the following characteristics:

Type process - - - - - - - - - - - - - - - - Cotton Gin
Annual production - - - - - - - - - - - - - 2,500 bales
Production rate - - - - - - - - - - - - - - 5 bales/hr
Exit gas volume
  Suction line - - - - - - - - - - - - - - - - - 9,000 acfm
  Burr line - - - - - - - - - - - - - - - - 5,000 acfm
  Incline cleaner line - - - - - - - - - - - 6,500 acfm
  Lint cleaner line - - - - - - - - - - - - 2,500 acfm
  Overflow line - - - - - - - - - - - - - - 4,000 acfm
  Condenser exhaust - - - - - - - - - - - - 6,000 acfm
Exit gas temperature (all streams) - - - - Ambient

Emission type	Particulates
Annual hours of operation	500
Annual emissions with no controls	14.5 tons
Average price per bale	$135

Control System

The control system will be composed of high efficiency cyclones and inline filters. They will be distributed on the emission sources as follows:

Emission Source	Control Equipment
suction line	4 cyclones in parallel
bur line	2 cyclones in parallel
incline cleaner line	2 cyclones in parallel
lint cleaner line	1 cyclone
overflow line	1 cyclone
exhaust of the lint cleaner	inline filter
exhaust of the condenser	inline filter

Particulate matter collected in the cyclones and filters is collected in a trash hopper with a skirt for disposal or for processing into fertilizer.

Control costs for the model plant are estimated to be:

	Low	High
Investment Cost	$40,000	$58,000
Annualized Cost	$ 5,500	$ 8,000

Overall efficiency of the control system will be about 90 percent. With this system in operation, emissions will be reduced from 14.5 T/yr to 1.4 T/yr.

No attempt was made in the calculation of control costs to estimate the value of the collected emissions due to the many variables involved. One source, however, has estimated that in Texas composted cotton trash has a fertilizer value of $7.50/T.

Impact

The 2,500 bales/yr produced in the model plant will yield about $337,500 in sales. The impact on the model plant from controlling emissions is:

	Low	High
Annualized Control Cost/Ton Particulates Collected ($/T)	$419.85	$606.87
Annualized Control Cost/Bale Produced ($/bale)	$ 2.20	$ 3.18
Annualized Control Cost as a Percent of Sales (%)	1.63%	2.36%

E.2.5.5 Estimated Industry Control Costs

By using the model plant control costs, control costs for the entire industry can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost	$177.9	$258.0
Annualized Cost	$ 24.5	$ 35.6

Because good information is not available on the number of plants controlling and their efficiency, no attempt is made here to distinguish between money that has already been spent and money that will be required to be spent. The cost figures presented are simply totals for the industry.

E.2.6 Ferroalloy(21-27)

E.2.6.1 Industry Production

Ferroalloy production in 1966 amounted to 650,000 tons from blast furnaces and 1,850,000 tons from electric furnaces.(21,22) The aluminothermic and silicothermic processes accounted for small additional production. Total capacity is estimated to be about 3,250,000 T/yr. The average value of shipments is estimated to be $87,800,000 ($135/T)(23) from blast furnaces and $426,000,000 ($230/T)(23) from electric furnaces.

E.2.6.2 Industry Emissions

Emissions vary widely in type and quantity, depending upon the particular ferroalloy being produced, type of furnace used, and the degree of carbon in the alloy. The particulate emissions from the ferroalloy industry amount to 275,000 tons per year at the present time.

E.2.6.3 Degree of Control of Emissions

Less than 20 percent of the plants producing ferroalloys are presently controlling. Much of this is probably for the recovery of product. Only about 50 percent of the effluent is captured at the furnace. From this exhaust gas, 95 percent of the particulates are removed.

E.2.6.4 Model Plants

Two model plants will be used in estimating the cost of control for the ferroalloy industry. Plant A employs a blast furnace primarily for the production of ferromanganese. Plant B employs an electric furnace for the production of more valuable ferroalloys. No distinction is made here between open and closed electric-arc furnaces. Also no consideration is given the carbon content in the alloy.

Characteristics - Plant A

The characteristics of this model plant are:

Type process - - - - - - - - - - - - - ferroalloy blast furnace
Annual output - - - - - - - - - - - - - 80,000 tons
Gas volume - - - - - - - - - - - - - - 40,000 acfm
Gas temperature - - - - - - - - - - - - 620°F
Emission type (27,28) - - - - - - - - - CO, SO_2, FeMn, SiO_2, FeSi
Annual hours of operation - - - - - - - 8760
Annual emissions with no control - - 7,200 tons
Average price per ton product - - - - $135.00

Control System - Plant A

The control system used to remove particulates is a high energy wet scrubber. The cleaned CO is available for fuel. With an assumed efficiency of 99 percent the annual particulate emissions from the model plant will be reduced from 7,200 tons to 72 tons. The estimated investment costs and annual costs are:

	Low	High
Investment Cost	\$25,000	\$60,000
Annualized Cost	\$50,800	\$76,700

Impact - Plant A

The 80,000 T/yr of ferromanganese produced in the model plant will yield about \$10,800,000/yr in sales. The impact on the model plant from controlling particulate emissions is:

	Low	High
Annualized Control Cost/ Ton Particulates Collected (\$/T)	\$7.13	\$10.76
Annualized Control Cost/ Ton of Production (\$/T)	\$0.64	\$ 0.96
Annualized Control Cost as a Percent of Sales	0.47%	0.71%

Characteristics - Plant B

The characteristics of Model Plant B are:

Type process	ferroalloy, open submerged-arc electric furnace
Annual output	51,000 tons
Gas volume	255,000 acfm(27)
Gas temperature	620°F
Emission type(26)	CO, SO_2, FeSi, FeMn, FeCr, SiO_2
Annual hours of operation	8,760
Annual uncontrolled emissions	4,600 tons
Annual price/ton product	\$230.00

Control System - Plant B

The control system for collection of particulates from the submerged-arc electric furnace is a high-energy wet scrubber. The CO is assumed to be converted to CO_2 by excess air introduced into the hood of the collection system. With an assumed efficiency of 99 percent, the annual particulate emission from the model plant will be reduced from 4,600 tons to 46 tons. The estimated investment costs and the annual costs of control are:

	Low	High
Investment Cost	$300,000	$625,000
Annualized Cost	$345,000	$525,000

Impact - Plant B

The 51,000 T/yr of ferroalloys produced in the model plant will yield about $11,700,000/yr in sales. The impact on the model plant from controlling particulate emissions is:

	Low	High
Annualized Control Cost/Ton Particulates Removed ($/T)	$75.76	$137.24
Annualized Control Cost/Ton of Production ($/T)	$ 6.76	$ 10.28
Annualized Control Cost as a Percent of Sales	2.94%	4.47%

E.2.6.5 Estimated Industry Control Costs

By using the model plant control costs, control costs for the entire industry can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost		
Blast furnaces	$ 0.2	$ 0.5
Electric furnaces	14.1	29.4
Total	$14.3	$29.9
Annualized Cost		
Blast furnaces	$ 0.4	$ 0.6
Electric furnaces	16.2	24.7
Total	$16.6	$25.3

No estimate was made of the money spent previously on control in the industry, but the amount is assumed to be very small in relation to the estimates given here.

E.2.7 Grain Mills and Grain Handling

E.2.7.1 Grain Mills (5,17,30-33)

E.2.7.1.1 Industry Production

The annual milling capacity of flour and feed mills, assuming a 7-day week operation, is about 6.5 billion bushels. Based on a 5-year average, annual milling is about 5.1 billion bushels which yielded about 2.16 billion cwt (100 lbs) of flour and 46 million tons of animal feed. Value of shipments of grain mill products in 1966 amounted to $9,242,000,000.

E.2.7.1.2 Industry Emissions

Total particulate emissions are estimated to be about 322,000 tons/year. Of these emissions, about 71 percent come from intake and cleaning operations and 29 percent come from milling and packing operations. There may also be an odor problem from some feed mills which use high-protein additives such as fish oil or meal. Grain dust from the mills has been linked with allergic reactions of large numbers of people in Minneapolis and New Orleans.

E.2.7.1.3 Degree of Control of Emissions

About 60 percent of the mills control particulate emissions from intake and cleaning operations. Efficiency of control on these operations ranges from 70 percent to 99 percent with an average of about 85 percent. About 90 percent of the mills control particulate emissions from milling and packaging operations. Efficiency of control on these operations ranges from 70 percent to 99 percent with an average of about 90 percent.

E.2.7.1.4 Model Plant

The model plant process includes initial intake of grain (this intake is not included in the report on grain handling and storage), cleaning of the grain, milling of grain, and packaging of product. Animal feed plants may include the additional step of pelletizing the meal using a binder. For purposes of estimating control costs, it makes no difference whether the model plant produces flour or animal feed. The emission sources are essentially the same.

Characteristics

The model plant has the following characteristics:

Type process - - - - - - - - - - - - - Flour or animal feed production
Annual output - - - - - - - - - - - - - 858,000 cwt
Exit gas volume
  Intake and cleaning - - - - - - - - 30,000 acfm
  Milling and packaging - - - - - - - 30,000 acfm
Gas temperature (all streams) - - - - Ambient ± 20°F
Emission type - - - - - - - - - - - - Particulates
Annual hours of operation - - - - - - 6800
Annual emissions with no controls
  Intake and cleaning - - - - - - - - 130 T/yr
  Milling and packaging - - - - - - - 130 T/yr
    Total - - - - - - - - - - - - - - 260 T/yr
Average price per cwt of product - - $3.00

Control System

A plant built after stringent emissions standards were imposed could be designed so that two control systems would control the emissions. However, if the standards were to be imposed on an existing plant, it is possible that the plant's layout and design would necessitate the installation of three, four, or more control systems. Since the model plant is to represent an average for the industry, it will have three control systems. Two systems will control the intake and cleaning operations and each will clean 15,000 acfm of gas. The third system will control the milling and packaging operations and will handle 30,000 acfm of gas.

Each control system will consist of a cyclone followed by a baghouse. The estimated control costs for the model plant are:

	Low	High
Investment Cost	$56,100	$90,600
Annualized Cost	$17,450	$22,350

In estimating the cost of control, no attempt was made to estimate economic benefits, if any, derived from capture of emissions. Analysis of the variables involved, to determine how much of the control costs incurred by the model plant is actually cancelled by any benefits derived from material recovery, is beyond the scope of this study.

With the above control system on the model plant, control efficiency for particulates will be about 99.5 percent and emissions will be reduced from 260 T/yr to 2 T/yr.

Impact

The 858,000 cwt produced in the model plant will yield about $2,574,000/yr in sales. The impact on the model plant from controlling emissions is:

	Low	High
Annualized Control Cost/Ton Particulates Collected ($/T)	$67.12	$85.96
Annualized Control Cost/Ton Product Produced ($/T)	$ 0.41	$ 0.52
Annualized Control Cost as a Percent of Sales (%)	0.68%	0.87%

E.2.7.1.5 Estimated Industry Control Costs

By using the model plant cost estimates, control costs for the entire industry can be estimated as:

	Millions of Dollars			
	Investment		Annualized	
	Low	High	Low	High
Facilities Presently Installed	$ 51.5	$113.3	$20.0	$28.4
Required Facilities	144.9	203.8	41.1	49.8
Industry Total	$196.4	$317.1	$61.1	$78.2

In making the above estimates, it was assumed that on the intake and cleaning operations 2,100 mills have cyclones presently installed and 175 mills have baghouses presently installed, and that on the milling and packaging operations 3,150 mills have cyclones presently installed and 1,050 mills have baghouses presently installed.

E.2.7.2 Grain Storage and Handling(5,17,28-31,34,35)

E.2.7.2.1 Industry Production

The storage capacity for grain is about 5.45 billion bushels in the United States. Based on a 5-year average, annual production of grains is about 7.02 billion bushels. About 5.1 billion bushels of this are milled in the United States and the remaining 1.92 billion bushels are exported as grain. There are about 11,147 storage elevators in the United States today; of these, 1,695 are located within SMSA's.

E.2.7.2.2 Industry Emissions

Industry emissions of particulates are estimated to be 800,000 T/yr. There may also be an odor problem in some locations.

E.2.7.2.3 Degree of Control of Emissions

About 60 percent of the elevators are estimated to control emissions. The average control efficiency is estimated to be 80 percent.

E.2.7.2.4 Model Plant

In the model plant, grain is unloaded into a receiving bin at or below ground level from trucks or railroad cars. It is transferred to the storage height by bucket elevators and distributed to storage bins by conveyors or a pneumatic system. The grain is returned to the ground level for loading by conveyors or gravity feed.

Characteristics

The model plant has the following characteristics:

Type process- - - - - - - - - - - - - -	Grain storage
Storage capacity- - - - - - - - - - - -	500,000 bushels
Annual grain handled- - - - - - - - - -	1,650,000 bushels
Gas volume- - - - - - - - - - - - - - -	45,000 acfm
Gas temperature - - - - - - - - - - - -	Ambient ± 20°F
Emission type - - - - - - - - - - - - -	Particulates
Annual hours of operation - - - - - - -	2,000
Annual emissions with no controls - -	150 tons

Control System

While some older elevators equal in size to the model plant might require more than one control system, in most cases one system would be sufficient. Therefore, the model plant will have one control system for handling the 45,000 acfm gas output.

The control system will consist of a cyclone followed by a baghouse equipped with cotton bags. The estimated control costs for the model plant system are:

	Low	High
Investment Cost	$35,400	$58,000
Annualized Cost	$ 6,850	$10,000

In calculating control costs, no attempt was made to estimate the value of recovered materials. Analysis of the variables involved in estimating their value is beyond the scope of this study.

With the above control system on the model elevator, control efficiency for collection of particulates will be about 99.5 percent. Emissions will be reduced from 150 T/yr to about 1 T/yr.

Impact

The impact on the model elevator from controlling emissions is:

	Low	High
Annualized Control Cost/Ton Particulates Collected ($/T)	$45.97	$67.78
Annualized Control Cost/Bushels Grain Handled ($/T)	$0.004	$0.006

Since a grain elevator is for collection and storage rather than a production facility, estimation of annualized control cost as a percent of sales is not a realistic indicator and has been omitted here.

E.2.7.2.5 Estimated Industry Control Costs

By using the model plant cost estimates, control costs for the entire industry can be estimated as:

	Millions of Dollars			
	Investment		Annualized	
	Low	High	Low	High
Facilities Presently Installed	$ 59.0	$161.1	$13.6	$ 27.4
Required Facilities	335.6	485.5	62.7	85.2
Industry Total	$394.6	$646.6	$76.3	$112.6

In making the above estimates, it was assumed that 60 percent of the elevators have cyclones presently installed and that 5 percent have baghouses.

E.2.8 Nitric Acid

E.2.8.1 Industry Production

Nitric acid production in 1967 amounted to 6,100,000 tons. Value of shipments for 699,800 tons transferred was $45,652,000. As stated in chapter 4, nitric acid is produced by ammonia oxidation. Of the total industrial capacity, 89.6 percent consists of the high pressure oxidation process. The remaining 11 percent of capacity consists of either the atmospheric or intermediate pressure oxidation processes.

E.2.8.2 Industry Emissions

Emissions for 1968 are estimated to be 110,000 tons of nitrogen oxides and 50,000 tons of particulates. The primary source of nitrogen oxides is the tail gas from the absorption tower. Nitrogen dioxide (NO_2) can be observed by the reddish-brown color of the plume. Even if the plume is colorless, nitric oxide (NO) may still be emitted.

Other emissions, primarily nitric acid mists, are considered insignificant.

E.2.8.3 Degree of Control of Emissions

About 15 percent of industrial capacity is controlling nitrogen oxides emissions through catalytic reduction techniques, with an average control efficiency(36) of 80 percent. Five plants are reported to use alkaline scrubbing(36) to reduce NO_x emissions.

E.2.8.4 Model Plant

Since the high pressure oxidation process accounts for approximately 90 percent of the total industry capacity, a single model plant employing this process will be used to represent the industry.

Characteristics

The model plant characteristics are:

Type process - - - - - - - - - - - - - -	High pressure oxidation
Annual output- - - - - - - - - - - - - -	68,000 tons
Production rate- - - - - - - - - - - - -	260 T/day
Annual hours of operation- - - - - - -	6,240
Gas volume - - - - - - - - - - - - - - - -	22,000 acfm
Absorption tower tail gas temperature-	90°F
Stack effluent temperature - - - - - -	500°F
Emission type- - - - - - - - - - - - - -	Nitrogen oxides
Annual emissions with no control - - -	1,940 tons
Average price per ton- - - - - - - - - -	$65.00

Control System

A two-stage catalytic reduction with an overall efficiency of 90 percent will be the assumed control technique. Control costs will include expenditures for the two stages of catalyst, a preheat burner, heat exchangers, and controls. Waste heat boilers are excluded. Natural gas will be the fuel for reducing the nitrogen oxides to nitrogen. Annualized costs include depreciation of investment at 10 percent and capital charges at 10 percent. Application of catalytic reduction to the model plant will result in the following costs:

	Low	High
Investment Cost	$60,000	$90,000
Annualized Cost	$39,500	$59,200

Generally, waste heat boilers are added to catalytic reduction systems for recovering heat. The economics usually involved in installing boilers will show that these pay for themselves if process steam is needed elsewhere in the nitric acid plant. Since the decision for installing these waste heat boilers depends on production needs, they have been excluded from the usual cost analyses for air pollution control.

With the control system on the model plant, annual emissions will be reduced from 1940 T/yr to 194 T/yr.

Impact

The 68,000 T/yr of nitric acid produced in the model plant will yield $4,420,000 in shipments. The impact on the model plant from controlling emissions is:

	Low	High
Annualized Control Cost/Ton NO_x Collected ($/T)	$22.62	$33.90
Annualized Control Cost/Ton Acid Produced ($/T)	$ 0.58	$ 0.87
Annualized Control Costs as a Percent of Sales (%)	0.89%	1.34%

E.2.8.5 Estimated Industry Control Costs

By using the control costs from the model plant, control costs for the entire industry can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost	$4.3	$6.5
Annualized Cost	$2.8	$4.3

No attempt was made above to differentiate between what has already been spent for control and what will have to be spent. The costs presented are simply the total cost of control to the industry.

E.2.9 Nonferrous Metallurgical Operations

E.2.9.1 Primary Aluminum Reduction(5,19,21,37-38)

E.2.9.1.1 Industry Production

An average of 2,541,200 tons of aluminum per year was produced during 1962-1966 with an annual value of shipments in 1966 equal to $1,496,221,000.

With the control system on the model plant, annual emissions will be reduced from 1940 T/yr to 194 T/yr.

Impact

The 68,000 T/yr of nitric acid produced in the model plant will yield $4,420,000 in shipments. The impact on the model plant from controlling emissions is:

	Low	High
Annualized Control Cost/Ton NO_x Collected ($/T)	$22.62	$33.90
Annualized Control Cost/Ton Acid Produced ($/T)	$ 0.58	$ 0.87
Annualized Control Costs as a Percent of Sales (%)	0.89%	1.34%

E.2.8.5 Estimated Industry Control Costs

By using the control costs from the model plant, control costs for the entire industry can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost	$4.3	$6.5
Annualized Cost	$2.8	$4.3

No attempt was made above to differentiate between what has already been spent for control and what will have to be spent. The costs presented are simply the total cost of control to the industry.

E.2.9 Nonferrous Metallurgical Operations

E.2.9.1 Primary Aluminum Reduction(5,19,21,37-38)

E.2.9.1.1 Industry Production

An average of 2,541,200 tons of aluminum per year was produced during 1962-1966 with an annual value of shipments in 1966 equal to $1,496,221,000.

E.2.9.1.2 Industry Emissions

Twenty-four plants contributed the following amounts of pollutants to the atmosphere:

Gaseous hydrogen fluoride	12,800 T/yr
Particulate (19.3% Fluorine)	92,500 T/yr
Gaseous sulfur dioxide	54,000 T/yr

Eight plants are located within Standard Metropolitan Statistical Areas.

E.2.9.1.3 Degree of Control Emissions

Industrywide control of emissions is estimated to be approximately 50 percent, or 12 plants. The efficiencies with which the 12 plants are controlling are:

Gaseous hydrogen fluoride	80% industrywide
Particulates (19.3% Fluoride)	80% industrywide
Gaseous sulfur dioxide	50% industrywide

E.2.9.1.4 Model Plant

A prebaked (Niagara) type electrolytic cell is used to dissolve the alumina. Carbon anodes for the electrolytic cell are produced on the plant site.

Characteristics

The model plant will have the following characteristics:

Type process	Aluminum ore reduction
Annual output	100,000 tons
Production rate	274 T/day
Annual hours of operation	8,750
Annual emissions with no control:	
Gaseous hydrogen fluorides	1,046 T/yr
Particulates (19.3% Fluorine)	2,960 T/yr
Gaseous sulfur dioxide	1,510 T/yr
Gas volumes:	
Prebaked electrolytic cell	822,000 scfm
Potroom	2,000,000 scfm
Anode plant furnace	25,000 scfm

Gas temperatures:

Prebaked electrolytic cell - - - 2000°F
Potroom- - - - - - - - - - - - - - 110°F
Anode plant furnace- - - - - - - 2000°F

Average sales price per ton - - - - $589

Control System

Emissions from the prebaked cells are first vented to 8 multicyclones (103,000 scfm each), then to an electrostatic precipitator (822,000 scfm), and finally to 8 three-stage floating bed cell scrubbers (103,000 scfm each).

Since emissions from prebaked cells often escape to a potroom containing the electrolytic cells, purification of the gases discharged from the potroom is necessary. This is accomplished by using two 1,000,000 scfm scrubbers.

The effluent gas stream from the anode plant furnace is vented to a two-stage floating bed scrubber.

Using the above control system will reduce gaseous hydrogen fluoride emissions from 1,046 T/yr to 10.46 T/yr, particulate emissions from 2,960 T/yr to 59.2 T/yr, and sulfur dioxide emissions from 1,510 T/yr to 75.5 T/yr.

The control system cost is estimated to be:

	Low	High
Investment Cost	$2,990,000	$5,807,000
Annualized Cost	$1,032,000	$1,626,000

Impact

The 100,000 T/yr produced in the model plant will yield about $58,900,000 in sales. The impact on the model plant is:

	Low	High
Annualized Control Cost/Total Tons Pollutants Controlled ($/T)	$192	$303
Annualized Control Cost/Ton Aluminum Produced ($/T)	$10.32	$16.26
Annualized Control Cost as a Percent of Sales (%)	1.75%	2.76%

E.2.9.1.5 Estimated Industry Control Cost

The control costs for the industry are:

	Millions of Dollars			
	Investment		Annualized	
	Low	High	Low	High
Systems Presently Installed	$16.9	$ 39.0	$ 6.2	$12.1
Future Requirements	60.9	112.0	20.6	30.2
Total	$77.8	$151.0	$26.8	$42.3

E.2.9.2 Primary Copper Smelting(21,22,38-41)

E.2.9.2.1 Industry Production

In 1966, a total of 19 copper smelters produced 1,581,107 tons of copper. The value of copper production in 1966 is estimated to be $1.7 billion, or $1,063 per ton.

E.2.9.2.2 Industry Emissions

An estimate of the total sulfur dioxide emissions is 2,950,000 tons per year. The range of sulfur dioxide emissions from individual smelters during 1968 was 11,000 to 536,000 tons per year.

Four of the 19 copper smelters are located within Standard Metropolitan Statistical Areas.

E.2.9.2.3 Degree of Control of Emissions

Five smelters are converting sulfur dioxide to sulfuric acid. In 4 of the 5 smelters, only the offgases which have high concentrations of sulfur dioxide are vented to the sulfuric acid plant. As a result, the collection efficiencies (by weight) of the four smelters range from 12 to 44 percent. The fifth smelter is controlling to an efficiency of 90 percent.

Sulfur dioxide emissions can also be controlled by producing concentrated sulfur dioxide (for use as such or as an intermediate to be used in production of another product) or elemental sulfur.

E.2.9.2.4 Model Plant

The model copper smelter plant to be used as a basis for cost estimating has one roaster, one reverberatory furnace, and two converters.(41) A cyclone dust collector recovers particulate matter to be resmelted.

Characteristics

Characteristics of the model plant are:

Type process- - - - - - - - - - - - Copper smelting
Annual output - - - - - - - - - - - 75,900 tons
Production rate - - - - - - - - - - 230 T/day
Emission type - - - - - - - - - - - Sulfur dioxide

Annual emissions
Roaster - - - - - - - - - - - - - 121,400 T/yr
Reverberatory - - - - - - - - - - 16,200 T/yr
Converter - - - - - - - - - - - - 93,400 T/yr
Total - - - - - - - - - - - - - 231,000 T/yr

Offgas after air dilutions	Temp.	Sulfur oxide
Roaster - - - - - - - - - - - - -	550°F	8.0 Vol. %
Reverberatory - - - - - - - - - -	550°F	0.9 Vol. %
Converter - - - - - - - - - - - -	640°F	3.8 Vol. %

Average price per ton of copper - $1,063

Control System

Offgases containing sulfur dioxide from the roaster and converters are combined and--after necessary gas stream preconditioning--are sent to a contact sulfuric acid plant. Offgases from the reverberatory furnace are vented to a limestone slurry to remove sulfur dioxide. With an overall efficiency of 91.3 percent, sulfur oxide emissions will be reduced from 231,000 tons per year to 19,173 tons. The estimated control system investment and annual costs are:

Investment Cost

Control of roaster & converter offgas	$10,000,000
Control of remaining offgas	640,000
	$10,640,000

Annualized Cost[*]

	Low	High
Control of roaster & converter offgas		$2,797,000
Control of remaining offgas		422,700
Total	$ 0	$3,219,000

The low cost of zero occurs when the sulfuric acid produced is sold at a profit; value of by-product sulfuric acid covers annual cost.

Impact

The cost attributable to the production of sulfuric acid (66° Baumé strength--equivalent tonnage of 100 percent acid is 312,000 tons per year) is $8.96 per ton of acid produced, or $36 per ton of copper produced. The ultimate impact of the control system upon an individual plant will depend upon the local market value of the sulfuric acid produced. Therefore, it would be unrealistic to estimate here the conventional impact indicators as was done for the other industries in this study.

E.2.9.2.5 Estimated Industry Control Cost

The control costs for the industry are estimated to be:

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[*] Includes capital charges calculated as 6-2/3 percent of the Investment Cost.

	Millions of Dollars		
	Investment[*]	Annualized[**]	
		Low	High
Systems presently installed	$ 10.6	$0	$ 3.2
Future requirements	$159.6	$0	$48.3
Industry total	$170.2	$0	$51.5

E.2.9.3 Primary Lead Smelting (22,38,41)

E.2.9.3.1 Industry Production

In 1967, six primary lead smelters produced a total of 401,151 tons of lead (some lead from secondary lead smelters is included). The range of production for the six smelters was 60,000 to 118,000 tons per year. The value of shipments for 1966 was $367,442,000, or approximately $916 per ton.

E.2.9.3.2 Industry Emissions

Estimates of industrial emissions to the atmosphere are 263,200 tons per year of sulfur dioxide and 33,000 tons per year of particulates. As explained in chapter 2 of the NESS report, the major sources of these emissions are the sintering operation and the blast furnace operation. Two lead smelters are located within SMSA's.

E.2.9.3.3 Degree of Control of Emissions

Two of the six primary lead smelters are recovering 47 percent and 96 percent of the sulfur oxides generated by their smelting process. The remaining 4 lead smelters do not recover sulfur dioxides.

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[*] Based upon typical model plants where no high-low variation was given.

[**] The "Low" annual control cost assumes all smelters will economically recover sulfuric acid. The "High" annual control cost assumes no value of recovered sulfuric acid.

To control sulfur dioxide emissions, smelters can convert the sulfur dioxide to sulfuric acid, concentrated sulfur dioxide (for use in other products) or elemental sulfur.

The degree of control of particulates is not known.

E.2.9.3.4 Model Plant

The model lead smelter plant has updraft sinter machines that produce 98 percent of the sulfur dioxide generated.(41) Offgases from the blast furnace and other smelter operations are very dilute.

Characteristics

The model plant has the following characteristics:

Type process - - - - - - - - - - - - - - - - - Lead smelting
Annual Output- - - - - - - - - - - - - - - - - 94,400 tons
Production Rate- - - - - - - - - - - - - - - - 286 T/day
Annual hours of operation- - - - - - - - - - 7,920
Emission type- - - - - - - - - - - - - - - - - sulfur dioxide, particulates

Annual emissions with no controls
  Sulfur dioxide - - - - - - - - - - - - - - - 46,000 tons
  Particulates - - - - - - - - - - - - - - - - 2,971 tons

Offgas from sintering after air dilution
  Temperature- - - - - - - - - - - - - - - - - 400°F
  Sulfur dioxide (vol.%) - - - - - - - - - - 5.00
  Sulfur trioxide (vol.%)- - - - - - - - - - .29
  Oxygen (vol.%) - - - - - - - - - - - - - - -12.00

Offgas from furnace after air dilution
  Temperature- - - - - - - - - - - - - - - - - 700°F
  Sulfur dioxide (vol.%) - - - - - - - - - - .06
  Oxygen (vol.%) - - - - - - - - - - - - - - - 4.00

Average price per ton of lead- - - - - - - $916

Control System

Particulate emissions are controlled by using two fabric filters (one filter for offgases from the furnace, the other filter for offgases from the sintering machines). A dust collector, such as a centrifugal separator, precedes the fabric filters. However, since it is common practice to use dust collectors for valuable particulate by-product recovery, they are considered process equipment, not air pollution control equipment. Effluent gases from the fabric filter associated with the sintering machines are vented to a contact sulfuric acid plant for removal of sulfur dioxide.

Particulate emissions will be reduced from 2,971 tons per year to 29.7 tons per year. Sulfur dioxide emissions will be reduced from 46,000 tons per year to 3,220 tons per year.

Control costs are estimated to be:

	Low	High
Investment Cost	$2,243,000	$2,300,000
Annualized Cost[*]	$ 0 (Value of by-product Sulfuric Acid covers annual costs)	$ 771,400 (By-product Sulfuric Acid has no value)

Impact

The ultimate impact depends on the local market value of the recovered sulfuric acid. Considering the model plant, if by-product sulfuric acid (sulfuric acid is 66° Baumé strength--equivalent tonnage of 100% acid is 65,900 tons per year) could be sold for more than $11.70 per ton (the cost to produce the acid at the contact plant), the acid production would pay for itself.

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[*] Includes capital charges calculated as 6-2/3 percent of the Investment Cost.

Assuming no value of the recovered sulfuric acid, the following indicators are given:

Annualized Cost/Ton Lead produced ($/T)	
Sulfuric Acid Plant	$7.6
Baghouses	$0.5
Total	$8.1

E.2.9.3.5 Estimated Industry Control Cost

The control costs for the industry are:

	Million of Dollars			
	Investment		Annualized[*]	
	Low	High	Low	High
Systems presently installed	$ 2.2	$ 2.3	$0	$0.8
Future requirements	$11.1	$11.5	$0	$3.9
Industry total	$13.4	$13.8	$9	$4.7

E.2.9.4 Primary Zinc Smelting (21,38,41)

E.2.9.4.1 Industry Production

The annual capacity of the 15 primary zinc smelters is 1,294,200 tons per year of zinc with a production rate of 1,021,000 tons per year.

E.2.9.4.2 Industry Emissions

Estimates of pollutant emissions are 640,000 tons per year of sulfur dioxide and 25,000 tons per year of particulates.

E.2.9.4.3 Degree of Control of Emissions

Nine of 15 primary zinc smelters recovered 370,800 tons of sulfur dioxide. The collection efficiencies varies from 49 to 98 percent (6 of the 9 smelters were controlling with efficiencies of 94-98 percent). Five smelters do not recover sulfur dioxide.

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[*] The "Low" annual control cost assumes economic recovery of all by-product sulfuric acid. The "High" annual control cost assumes no value of the recovered sulfuric acid.

Control of sulfur dioxide emissions can be accomplished through converting sulfur dioxide to sulfuric acid, concentrated sulfur dioxide, or elemental sulfur.

Control of particulate emissions is estimated to be 50 percent.

E.2.9.4.4 Model Plant

The zinc smelter model plant has the following process equipment: roaster, dryer, sinter machine, coker, and retort.(41) Offgases from the roaster have a high concentration of sulfur oxides. Offgas concentrations from other operations are weak.

Characteristics

The model plant has the following characteristics:

Type process - - - - - - - - - - - - - Zinc smelting
Annual Output - - - - - - - - - - - - 113,200 tons
Production Rate - - - - - - - - - - - 343 T/day
Annual hours of operation - - - - - 7,920
Emission type - - - - - - - - - - - - Sulfur dioxide, Particulates
Annual emissions with no controls:
  Sulfur Dioxide - - - - - - - - - - 60,600 tons
  Particulates - - - - - - - - - - - 5,500 tons
Offgas from roasting after air dilution:
  Temperature - - - - - - - - - - - 600°F
  Sulfur Oxides (vol.%) - - - - - - 7.2
  Oxygen (vol.%) - - - - - - - - - - 10.9
Offgas from sintering after air dilution:
  Temperature - - - - - - - - - - - 500°F
  Sulfur oxides (vol.%) - - - - - - .05
  Oxygen (vol.%) - - - - - - - - - - 18.0

Control System

Sulfur dioxide emissions from the roaster are controlled by venting offgases to a contact sulfuric acid plant. Other offgases, containing particulates and weak concentrations of sulfur dioxide, are sent to a fabric filter and then discharged to the atmosphere.

Particulate emissions will be reduced from 5,500 tons to 55 tons per year. Sulfur dioxide emissions will be reduced from 60,600 tons to 4242 tons per year.

Control costs are estimated to be:

	Low	High
Investment Cost	$4,700,000	$5,200,000
Annualized Cost*	$ 0 (Value of By-product Sulfuric Acid covers annual costs)	$1,464,000 (By-product Sulfuric Acid has no value)

Impact

Local supply and demand for the by-product sulfuric acid would have to be known before the impact of air pollution control could be assessed. The operating cost associated with the baghouses and sulfuric acid plant is $13 per ton of zinc (assuming no value for recovered sulfuric acid or recovered zinc oxides).

E.2.9.4.5 Estimated Industry Control Cost

The control costs for the industry are:

	Millions of Dollars			
	Investment		Annualized**	
	Low	High	Low	High
Systems presently installed	$28.2	$31.2	$0	$ 8.8
Future requirements	$37.6	$41.6	$0	$11.7
Industry total	$65.8	$72.8	$0	$20.5

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[*] Includes capital charges calculated as 6-2/3 percent of Investment Cost.

[**] The "Low" annual control cost assumes economic recovery of all by-product sulfuric acid. The "High" annual control cost assumes no value of the recovered sulfuric acid.

E.2.9.5 Secondary Nonferrous Metallurgical Industry(5,21,33)

Secondary copper, lead, and zinc production are the only secondary nonferrous operations considered. Secondary aluminum and secondary precious metals production are omitted.

E.2.9.5.1 Industry Production

Annual value of shipments in 1963 was:

Secondary copper and alloys	$222 million
Secondary lead and alloys	$192 million
Secondary zinc and alloys	$ 43 million

No reliable figures concerning industry production rates were obtainable.

E.2.9.5.2 Industry Emissions

Gross estimates of particulate emissions for the secondary nonferrous industries are:

Secondary copper and alloys	14,000 T/yr
Secondary lead and alloys	22,000 T/yr
Secondary zinc and alloys	3,500 T/yr

Of the 20 major secondary copper smelters, 18 smelters are within SMSA's. Of the 64 major secondary lead smelters, 62 are within SMSA's. Of the 12 major secondary zinc smelters, 10 are within SMSA's.

E.2.9.5.3 Degree of Control of Emissions

It is estimated that 75-90 percent of the secondary nonferrous industries are controlling particulate emissions to 70-99 percent efficiency. Economic motivation accounts for much of the present degree of emission control, since collected particulate matter can be of value.

E.2.9.5.4 Model Plant

To estimate total industry air pollution control costs for secondary copper, lead, and zinc operations, a model plant for each operation will be used as a basis for control cost projections.

Characteristics--Secondary Copper Model Plant

The secondary copper model plant will have the following characteristics:

Type process - - - - - - - - - - - - - - - Direct fire furnaces (reverberatory and rotary)

Process size:

  Reverberatory furnaces - - - - - - 2 at 50 tons/heat

  Rotary furnaces - - - - - - - - - - - 2 at 17½ tons/heat

Annual output:

  Reverberatory furnace - - - - - - - 11,000 tons

  Rotary furnace - - - - - - - - - - - 4,000 tons

  Total - - - - - - - - - - - - - - - - - 15,000 tons

Annual hours of operation:

  Reverberatory furnace - - - - - - - 1,760

  Rotary furnace - - - - - - - - - - - 1,840

Gas volume:

  Reverberatory furnace - - - - - - - 15,000 scfm

  Rotary furnace - - - - - - - - - - - 15,000 scfm

Emission type - - - - - - - - - - - - - Particulates

Gas stream temperature:

  Reverberatory furnace outlet - - - 2,000°F

  Rotary furnace outlet - - - - - - - 2,000°F

Annual emissions with no controls:

  Reverberatory furnace - - - - - - - 291 tons particulates

  Rotary furnace - - - - - - - - - - - 61 tons particulates

  Total - - - - - - - - - - - - - - - - - 356 tons

  Average price of copper per tons - $920

Characteristics--Secondary Lead Model Plant

The secondary lead model plant will have the following characteristics:

Type process - - - - - - - - - - - - - - - Direct fire furnace

Annual output - - - - - - - - - - - - - - 5,187 T/yr

Production rate - - - - - - - - - - - - - 2,500 lb/hr

Annual hours of operation - - - - - - - 4,150

Gas volume - - - - - - - - - - - - - - - - 3,060 scfm

Emission type - - - - - - - - - - - - - - - - Particulates

Annual emissions with no controls - - - - - 270 tons

Average price per ton of lead - - - - - - - $320

Characteristics--Secondary Zinc Model Plant

The secondary zinc model plant will have the following characteristics:

Type Process - - - - - - - - - - - - - - - - Indirect fire furnace (a muffle furnace which essentially includes a melting pot and a retort with condenser).

Production rate - - - - - - - - - - - - - - 107 tons/10-14 day batch (assume 17 14-day batches per year with one week between batches).

Annual output - - - - - - - - - - - - - - - 1,815 tons

Annual hours of operation - - - - - - - - - 5,712

Emission type - - - - - - - - - - - - - - - Particulates

Gas stream volume and temperature:

At sweat door, 3,200 cfm, 900°F

At dross door, 5,500 cfm, 900°F

At tapping spout, 8,700 cfm, 1800°F

Annual emissions with no controls - - - - 14 tons

Average price of zinc per ton - - - - - - $280

Control System

The control system for each model plant will consist of gas stream preconditioning equipment such as water sprays and U-tube coolers followed by a baghouse.

The collected particulates are withdrawn from the baghouse hopper and either recycled through the production process, sold to customers (e.g., small chemical processing plants), or disposed of in other ways.

The estimated control costs for each model plant are:

	Low	High
Secondary Copper:		
Investment Cost	$129,800	$216,400
Annualized Cost	$ 39,200	$ 65,300
Secondary Lead:		
Investment Cost	$ 57,300	$ 95,500
Annualized Cost	$ 17,300	$ 28,800
Secondary Zinc:		
Investment Cost	$ 59,500	$ 99,100
Annualized Cost	$ 17,900	$ 29,900

The efficiency of collection of the control system will be 99^+ percent. Particulate emissions in each model plant will be reduced to these levels:

	Before control	After control
Secondary Copper	356 T/yr	4 T/yr
Secondary Lead	270 T/yr	3 T/yr
Secondary Zinc	14 T/yr	<1 T/yr

Impact

Annual production in each model plant will yield the following amounts in sales:

	Production	Value of sales
Secondary Copper	15,000 T/yr	$13,800,000
Secondary Lead	5,187 T/yr	$ 1,660,000
Secondary Zinc	1,815 T/yr	$ 508,200

The impact of control on each model plant is:

Secondary copper	Low	High
Annualized Control Cost/Ton Particulates Collected ($/T)	$111	$186
Annualized Control Cost/Ton Copper Produced ($/T)	$2.61	$4.35
Annualized Control Cost as a Percent of Sales (%)	0.28%	0.47%

Secondary Lead	Low	High
Annualized Control Cost/Ton Particulates Collected ($/T)	$65	$108
Annualized Control Cost/Ton Lead Produced ($/T)	$3.33	$5.55
Annualized Control as a Percent of Sales (%)	1.04%	1.73%
Secondary Zinc		
Annualized Control Cost/Ton Particulates Collected ($/T)	$1279	$2136
Annualized Control Cost/Ton Zinc Produced ($/T)	$9.86	$16.47
Annualized Control Cost as a percent of sales (%)	3.52%	5.88%

E.2.9.5.5 Estimated Industry Control Costs

By using the model plants, control costs for the industry can be estimated as:

	Millions of Dollars			
	Investment		Annualized	
	Low	High	Low	High
Secondary Copper				
Systems presently installed	$ .65	$ 1.08	$ .20	$ .33
Future requirements	9.09	15.15	2.74	4.57
Industry total	9.74	16.23	2.94	4.90
Secondary Lead				
Systems presently installed	$ .34	$ .57	$ .10	$ .17
Future requirements	5.73	9.55	1.73	2.88
Industry total	6.07	10.12	1.83	3.05
Secondary Zinc				
Systems presently installed	$ .24	$ .40	$ .07	$ .12
Future requirements	2.20	3.37	.66	1.11
Industry Total	2.44	3.77	.73	1.23

The sum of the three totals above is as follows:

	Low	High
Investment	$18.25	$30.12
Annualized	$ 5.50	$ 9.18

E.2.10 Petroleum Refining(5,18,33,42-48)

E.2.10.1 Industry Production

Annual capacity of petroleum refineries is estimated to be 4.04 billion barrels of crude/year (11 million bbl/calendar day). Average annual production for the preceding five years is estimated to be 3.3 billion barrels crude(9.0 million bbl/calendar day). Value shipments of petroleum products in 1966 was $18.7 billion. On January 1, 1968, there were an estimated 269 operating refineries in the United States.

E.2.10.2 Industry Emissions

Emissions from petroleum refineries are estimated to be 170,000 T/yr of particulates, 2,100,000 T/yr of sulfur oxides, and 1,950,000 T/yr of hydrocarbons. Nitrogen oxides, carbon monoxide, and malodorous materials are also emitted.

E.2.10.3 Degree of Control of Emissions

Most, if not all, refineries control particulate emissions from catalytic cracking operations by using cyclones to capture valuable catalyst. These cyclones must be considered process equipment and not air pollution control equipment, however, since their use is economically advantageous to the refineries. About 23 refineries are controlling particulate emissions to at least 90 percent efficiency by using electrostatic precipitators. About 45 refineries representing 46 percent of total refining capacity recover sulfur from refinery process gas. These 45 refineries remove about 90 percent of the sulfur in the process gas, an amount which is about

70 percent of sulfur emitted from these refineries. As of August 1968, about 75 percent of the operating catalytic cracking units in refineries were equipped with waste heat boilers which convert potential CO emissions into fuel. Use of the boilers is in general economically advantageous, with pollution control a secondary benefit. Because of the trend toward installing the boilers, CO emissions from catalytic crackers should be negligible in the very near future. No estimates are available on the degree of hydrocarbon control in the industry. Refineries in the Los Angeles area, however, are known to control hydrocarbons extensively.

E.2.10.4 Model Plant

The petroleum refinery today is a very complex production system containing many processes. Only major emission sources in the refinery will be considered for estimation of control costs, for consideration of all potential emission sources is beyond the scope of this study. Three different model plants will be used to represent different operations which are major emission sources within the refinery.

Characteristics--Model Plant A

Model Plant A will be used to represent the fluidized catalytic cracking process of all refineries large enough to be capable of supporting such a process. The size of the refinery which would have the model catalytic cracker is 80,000 bbl crude/day. Model Plant A will have the following characteristics:

Type process	Fluidized catalytic cracking
Annual feed input	14,600,000 bbl
Feed input rate	40,000 bbl/day
Gas volume	95,000 acfm
Gas temperature	500°F
Emission type	particulates

Annual emissions with no controls - - - - - - - - - - - - - - - - - - 1,260 tons

Annual hours of operation - - - - - - - - 8,400

Control System--Model Plant A

The control system will consist of an electrostatic precipitator with an efficiency of 90 percent. With this system in operation particulate emissions will be reduced from 1,260 T/yr to 117 T/yr. The estimated cost of control for this model plant is:

	Low	High
Investment Cost	\$68,000	\$110,000
Annualized Cost	\$11,900	\$ 19,800

Impact--Model Plant A

No attempt will be made to estimate the value of products from the fluidized catalytic cracking operation because of the wide range of potential products and the extent of recycling of various streams.

The impact on Model Plant A is:

	Low	High
Annualized Control Cost/Ton Particulates Collected (\$/T)	\$11.5	\$19.2
Annualized Control Cost/bbl Feed charged (\$/bbl)	$\$8.5 \times 10^{-4}$	$\$14.1 \times 10^{-4}$

Characteristics--Model Plant B

Model Plant B does not represent an isolated process segment within a refinery as did Model Plant A. Model Plant B instead will represent an entire refinery and will be used to estimate cost of control of sulfur compounds in process gas streams.

Model Plant B will have the following characteristics:

Type process - - - - - - - - - - - - - - - - - - Refinery

Annual crude input - - - - - - - - - - - - - - 12,410,000 bbl

Crude input rate - - - - - - - - - - - - - - - 34,000 bbl/day

Process gas volume - - - - - - - - - - - - - - 10,000 acfm

Process gas temperature - - - - - - - - - - Ambient

Emission type	H_2S, or SO_2 if gas is burned
Annual emissions with no control	8,000 tons of SO_2
Annual hours of operation	8,400

Control System--Model Plant B

Control of SO_2 emissions will be accomplished by use of a sulfur recovery plant which converts SO_2 to elemental sulfur. Production of sulfur from the plant will be 10 T/day or 3,500 T/yr. About 97 percent of the entering SO_2 in the gas stream is absorbed. Of this amount, 93 percent is converted to sulfur. Overall control of emissions is then 90 percent. With the recovery plant in operation, emissions will be reduced from 8,000 T/yr of SO_2 to 800 T/yr of SO_2. Estimated cost of the recovery plant is:

	Low	High
Investment Cost	$200,000	$400,000
Annualized Cost	$ 75,000	$150,000

The above costs do not include credits for value of sulfur produced.

Impact--Model Plant B

The ultimate impact on the model plant will depend on the local market for sulfur, and therefore it is not realistic to try to estimate impact on the model plant.

Characteristics--Model Plant C

Model Plant C will be used for estimating cost of control of gasoline and crude storage emissions and waste water separator emissions.

The model plant will have the following characteristics:

Type process	Refining
Annual crude input	12,300,500 bbl
Crude input rate	33,700 bbl/day
Annual gasoline production	6,314,500 bbl
Gasoline production rate	17,300 bbl/day

Waste water rate	33,700 bbl/day
Storage capacity:	
Crude	500,000 bbl
Gasoline	780,000 bbl
Emission type	hydrocarbons
Annual emissions with no control:	
Cone roof tanks	2,640 T/yr
Waste water separators	760 T/yr
Total	3,400 T/yr
Annual hours of operation	8,760

Control System--Model Plant C

About 50 percent of the storage tanks in the model plant are the floating roof type which adequately prevent hydrocarbon emissions; the other 50 percent are fixed roof tanks. Control of hydrocarbon emissions from these tanks will be accomplished by replacing them with floating roof tanks. Emissions from waste water separators will be controlled by placing floating roof covers on the separators. Estimated costs of the control systems are:

	Low	High
Investment Cost		
Crude storage	$370,000	$ 600,000
Gasoline storage	516,000	840,000
Waste water separators	76,000	92,000
Total	$962,000	$1,532,000
Annualized Cost		
Crude storage	$ 57,000	$ 87,000
Gasoline storage	79,000	122,000
Waste water separators	11,000	13,000
Total	147,000	$ 222,000

Replacing the fixed roof tanks with floating roof tanks should result in an emission reduction of 80 percent. Control on the waste water separator should result in an emission reduction of 90 percent. Hydrocarbon emissions from these sources should thus be reduced from 3,400 T/yr to 604 T/yr.

No credit is given for value of the hydrocarbons contained by the controls.

Such an estimate is beyond the scope of this study.

Impact--Model Plant C.

The impact on Model Plant C is:

	Low	High
Annualized Control Cost/Ton Hydrocarbons Controlled ($/T)	$52.6	$79.4
Annualized Control Cost/bbl Processed in refinery ($/bbl)	$0.012	$0.018

E.2.10.5 Estimated Industry Control Costs

By using the model plant control costs, cost of control for the industry can be estimated as:

Investment Cost

	Millions of Dollars	
	Low	High
Fluidized catalytic cracking		
Systems presently installed	$1.56	$ 2.53
Required Systems	6.39	10.34
Total	$7.95	$12.87
Sulfur recovery from process gas		
Systems presently installed	$24.40	$48.80
Required systems	29.80	59.60
Total	$54.20	$108.40
Gasoline and crude storage, waste water separators	258.78	412.11
TOTAL	$320.93	$533.38

Annualized Cost

	Low	High
Fluidized catalytic cracking		
Systems presently installed	$ 0.27	$ 0.46
Required systems	1.12	1.86
Total	$ 1.39	$ 2.32

	Low	High
Sulfur recovery from process gas		
Systems presently installed	$ 9.15	$18.30
Required systems	11.18	22.35
Total	$20.33	$40.65
Gasoline and crude storage, waste water separators	39.54	59.72
TOTAL	$61.26	$102.69

The above industry costs are cost of control only for the specific sources designated in this report. The requirement for control of other less important emission sources would, of course, increase the costs.

E.2.11 Phosphate Fertilizer (5,49-52)

E.2.11.1 Industry Production

Annual capacity and average annual production for the 233 plants which produce the three types of phosphate fertilizers are:

	Annual capacity	Annual production-1967
Normal superphosphate (NSP)	3,284,000 T	1,184,000 T
Triple superphosphate (TSP)	5,810,000 T	1,481,000 T
Diammonium phosphate (DAP)	6,599,000 T	1,747,000 T
Total	15,693,000 T	4,412,000 T

All weights in the above table and all subsequent product weights given in this report are in terms of phosphorus pentoxide (P_2O_5) content. The actual weights of the fertilizers produced would be greater.

E.2.11.2 Industry Emissions

Particulate emissions from the phosphate fertilizer plants are estimated to be 259,000 T/yr. Flouride emissions are estimated to be 53,000 T/yr.

E.2.11.3 Degree of Control of Emissions

All of the phosphate fertilizer plants control emissions to some degree. The control efficiency ranges from 60-99 percent in all three types of plants. The estimated average efficiency of control is 90 percent in the NSP plants and 95 percent in the TSP and DAP plants.

E.2.11.4 Model Plants

Because three different types of fertilizers are produced, three model plants will be used to represent the industry.

Characteristics--NSP Model Plant

The NSP model plant will have the following characteristics:

Type process - - - - - - - - - - - - - - NSP production
Annual output - - - - - - - - - - - - - 6,360 tons
Production rate - - - - - - - - - - - - 2.17 T/hr
Annual hours of operation - - - - - 2,930
Gas volumes:
  From reactor and den - - - - - 590 acfm
  From dryer - - - - - - - - - - - - 2,320 acfm
  From cooler and screen - - - - 90 acfm
  Total 3,000 acfm
Gas temperatures:
  From reactor and den - - - - - 160°F
  From dryer - - - - - - - - - - - - 240°F
  From cooler and screen - - - - 130°F
Emission type - - - - - - - - - - - - - Particulates, Fluorides
Annual emissions with no controls:
  Particulates - - - - - - - - - - - 36.6 tons
  Fluorides - - - - - - - - - - - - - 0.5 tons

Control System--NSP Model Plant

NSP plants are on the average the oldest phosphate fertilizer plants. Because some of the plants were built before strict air pollution standards were in force, their layout may be such that more than one control system is required for emission control. Because of the relatively small volume of gas exiting the model plant, however, it will be assumed that the model plant layout is such that one control system can handle all emission sources.

The control system will consist of a cyclone followed by a venturi scrubber followed by a spray tower.

Estimated costs of the control system are:

	Low	High
Investment Cost	$11,200	$27,300
Annualized Cost	$ 3,050	$ 5,250

Efficiency of the control system should be about 95 percent. With the control system in operation, particulate emissions should be reduced from 36.6 T/yr to 1.8 T/yr and flouride emissions from 0.5 T/yr to 0.025 T/yr.

In calculating the above costs, no attempt was made to assess the value of recovered materials, if any.

Impact--NSP Model Plant

The impact of control on the NSP model plant is:

	Low	High
Annualized Control Cost/Total Tons Pollutants Collected ($/T)	$86.4	$148.7
Annualized Control Cost/Ton Fertilizer Produced ($/T)	$ 0.48	$ 0.82

Characteristics--TSP Model Plant

The TSP model plant will have the following characteristics:

Type process - - - - - - - - - - - - - TSP production
Annual output - - - - - - - - - - - - 72,720 tons
Production rate - - - - - - - - - - - 30.15 T/hr
Annual hours of operation - - - - - 2,412
Gas volumes:
  From blunger and screen - - - - 62,450 acfm
  From cooler, dryer, and reactor 36,600 acfm
  Total 99,050 acfm
Gas temperatures:
  From blunger and screen - - - - 150°F
  From cooler, dryer, and reactor 200°F
Emission type - - - - - - - - - - - - Particulates, Fluorides
Annual emissions with no control:
  Particulates - - - - - - - - - - 4,156 tons
  Fluorides - - - - - - - - - - - - 18.2 tons

Control System--TSP Model Plant

There are many combinations of control equipment and control systems used to control emissions in the TSP plants. For the model, two separate control systems will be used. One will clean the gases from the blunger and screen; the other will clean the bases from the cooler, dryer, and reactor.

Each control system will consist of a cyclone followed by a venturi scrubber followed by a spray tower. Estimated costs of the control system are:

	Low	High
Investment Cost	$111,500	$275,000
Annualized Cost	$ 53,400	$ 78,600

Efficiency of the control system should be about 95 percent. With the control systems in operation particulate emissions should be reduced from 4,156 T/yr to 208 T/yr and fluoride emissions from 18.2 T/yr to 0.9 T/yr.

In calculating the above costs, no attempt was made to assess the value of recovered materials, if any.

Impact--TSP Model Plant

The impact of control on the TSP model plant is:

	Low	High
Annualized Control Cost/Ton Pollutants Collected ($/T)	$13.46	$19.82
Annualized Control Cost/Ton Fertilizer Produced ($/T)	$ 0.73	$ 1.08

Characteristics--DAP Model Plant

The DAP model plant will have the following characteristics:

Type process - - - - - - - - - - - - - DAP production
Annual output - - - - - - - - - - - - 25,900 tons
Production rate - - - - - - - - - - - 15 T/yr
Annual hours of operation - - - - - 1,860
Gas Volumes:
    From reactor-granulator - - - - 8,300 acfm

From dryer - - - - - - - - - - - - -18,650 acfm

From cooler - - - - - - - - - - - - 7,350 acfm

Total 34,300 acfm

Gas temperatures:

From reactor-granulator - - - - -200°F

From dryer - - - - - - - - - - - - -165°F

From cooler - - - - - - - - - - - -140°F

Emission Type - - - - - - - - - - - - - -Particulates, Fluorides

Annual emission with no controls:

Particulates - - - - - - - - - - - -1,500 tons

Fluorides - - - - - - - - - - - - -2.4 tons

Control System--DAP Model Plant

As was true of the TSP plants there are many combinations of control equipment and control systems used in DAP plants. For the model DAP plant, three separate control systems will be used. One will clean the gases from the reactor-granulator, one will clean the gases from the dryer, and one will clean the gases from the cooler.

Each control system will consist of a cyclone followed by a venturi scrubber followed by a spray tower. Estimated costs of the control system are:

	Low	High
Investment Cost	$60,000	$149,000
Annualized Cost	$18,800	$ 30,800

Efficiency of the control systems will be about 95 percent. With the control systems in operation, particulate emissions will be reduced from 1,500 T/yr to 75 T/yr and fluoride emissions from 2.4 T/yr to 0.12 T/yr.

In calculating the above costs, no attempt was made to assess the value of recovered materials, if any. It should also be mentioned that no costs for equipment used to control ammonia emissions were included. Control of ammonia emissions is an industrial hygiene and economic problem for the plant. Therefore, any equipment used in ammonia emission control must be considered production equipment, not air pollution control equipment.

Impact--DAP Model Plant

The impact of control on the DAP model plant is:

	Low	High
Annualized Control Cost/Ton Pollutants Collected ($/T)	$13.19	$21.61
Annualized Control Cost/Ton DAP Produced ($/T)	$ 0.73	$ 1.19

E.2.11.5 Estimated Industry Control Costs

Because of insufficient data on the degree of control now practiced in the industry, no attempt will be made to differentiate between funds already spent for control systems and funds that will be required to be spent. Industry control costs are estimated to be:

	Millions of Dollars			
	Investment Cost		Annualized Cost	
	Low	High	Low	High
NSP	$1.76	$4.29	$0.48	$0.82
TSP	2.45	6.05	1.17	1.73
DAP	3.24	8.05	1.01	1.66
Total	$7.45	$18.39	$2.66	$4.21

E.2.12 Phosphoric Acid

E.2.12.1 Industry Production

Production of phosphoric acid (H_3PO_4) in 1967 amounted to 3,752,000 tons (100 percent, P_2O_5)$^{(53)}$ from the wet process and 1,039,000 tons (100 percent P_2O_5) from the thermal process. The value of shipments for 1967 is reported as follows:

Wet process acid . . . $76,000,000
Thermal process acid . $41,000,000

The individual figures for shipments for the two types of process acid are unknown; however, the total shipped was 1,077,000 tons.

Average price for 1967 was $108 per ton phosphorus pentoxide (P_2O_5) shipped. High purity food-grade acid in 1969 costs approximately $138 per ton; fertilizer acid costs $106 per ton.(53)

E.2.12.2 Industry Emissions

Particulate emissions from the wet process are estimated to be 5,000 tons per year. The wet process is estimated to emit 40 tons per year of fluorides either as hydrogen fluoride (HF) or silicon tetrafluoride (SiF_4).

The thermal process emits an estimated 1,100 tons per year of acid mists in the form of H_3PO_4. Also, small amounts of hydrogen sulfide are emitted in the gases vented from the acid treater of the process.

E.2.12.3 Degree of Control of Emissions

In the thermal process, present control of acid mists ranges from 95 to 99.9 percent with an average control efficiency of 97.7 percent.(54) Furthermore, all plants have installed highly efficient control devices to prevent acid mist emission, which is a direct product loss. Such collectors are considered production equipment.

Many plants producing food-grade phosphoric acid from the thermal process do not control the hydrogen sulfide emission which results from the treating of the raw acid to remove arsenic and lead. Four plants,(54) however, are reported either to pipe the acid treater gas into the phosphorous furnace or to clean the gas with a packed tower.

In the wet process, the range of control efficiency for particulates and fluorides ranges from 55 to 99 percent. The average control efficiencies practiced are 90 percent for particulates and 93 percent for fluorides.

In newer wet process plants, vacuum evaporation in the acid concentration step of the process will reduce the potential fluoride emission by removing 30-40 percent of the original fluorine in the rock used as raw material. The fluorine is collected as a solution of hydrofluosilic acid.(55)

E.2.12.4 Model Plant

Two model plants will be used to estimate the cost of control for the thermal and wet processes.

Characteristics

The model plant characteristics are:

	Thermal	Wet Process
Annual Output (100% P_2O_5)	34,500 tons	39,300 tons
Production rate (100% P_2O_5)	115 T/yr	131 T/yr
Annual hours of operation	7,200	7,200
Gas volume	500 acfm	32,000 acfm
Gas temperature	180°F	70-90°F
Emission type	H_2S	Particulates & Fluorides
Emissions with no control		
(a) H_2S	10-2,500	---
(b) Particulates	---	1,000 T/yr
(c) Fluorides	---	10 T/yr
Average price per ton	\$138	\$106

Control System

A simple packed tower with an appropriate scrubbing medium bearing sulfations will be the control techniques for H_2S removal for the thermal process. If iron sulfates are used to precipitate the sulfide ion in the scrubber, the resultant material (iron sulfide) can be safely buried without an odor or other pollution problem. The H_2S gas may be recycled back into the phosphorous furnace and burned. Costs for this alternative control technique are unknown.

The control technique assumed for wet processes will be a medium-energy scrubber which will remove effectively 90-99 percent of the uncontrolled particulates and fluorides. The cross-flow packed tower or the eductor venturi are adequate for scrubbing operations.

Collected waste material from scrubbers on wet process plants is transferred to a gypsum storage pond. Evolution of fluoride gas from these ponds constitutes an emission source. Maintaining a pH of approximately 4.0 with the addition of slaked lime to the pond can reduce this emission. Costs have not been estimated for disposal or treatment of gypsum ponds.

Application of the above control techniques to the respective processes will result in the following costs:

	Thermal		Wet Process	
	Low	High	Low	High
Investment cost	$2,500	$4,000	$9,000	$30,000
Annualized cost	$ 670	$1,070	$8,100	$17,000

Annualized costs include depreciation of investment at 10 percent and capital charges at 10 percent.

With the control systems, model plants annual emissions would be reduced as follows:

(a) H_2S from 2,500 to 250 ppm.
(b) Particulates from 1,000 T/yr to 50 T/yr.
(c) Fluorides from 10 T/yr to 0.5 T/yr.

Impact

In the thermal process, the 34,500 tons of P_2O_5 will yield $4,761,000 in shipments. In the wet process, 39,300 tons of P_2O_5 will yield $4,166,000 in shipments. The impact on the model plants from controlling emissions is:

	Thermal	
	Low	High
Annualized Control Cost/Ton acid produced ($/T)	$0.02	$0.03
Annualized Control Cost as a percent of sales (%)	0.01%	0.02%

	Wet Process	
	Low	High
Annualized Control Cost/Ton Particulates Collected ($/T)	$8.53	$17.89
Annualized Cost/Ton Fluorides Collected ($/T)	$852	$1,789
Annualized Control Cost/Ton Acid Produced ($/T)	$0.21	$0.43
Annualized Control Cost as a Percent of Sales (%)	0.19%	0.41%

Any value for product recovered in the particulate material for the wet process has not been considered in the annualized cost of control, or in the impact analysis.

E.2.12.5 Estimated Industry Control Costs

By using the control costs from the model plant, control costs for the entire industry can be estimated as:

	Millions of Dollars			
Thermal Process	Investment Cost		Annualized Cost	
	Low	High	Low	High
Systems Presently Installed	$0.010	$0.016	$0.0027	$0.0043
Required Systems	0.045	0.072	0.0121	0.0193
Total	$0.055	$0.088	$0.0148	$0.0236
Wet Process	Investment Cost		Annualized Cost	
	Low	High	Low	High
Systems Presently Installed	$0.36	$1.2	$0.324	$0.68
Required Systems	0.09	0.3	0.081	0.17
Total	$0.45	$1.5	$0.405	$0.85

By summing the total costs for the two processes, total estimates for the entire industry are estimated as:

Both Processes	Investment Cost		Annualized Cost	
	Low	High	Low	High
Systems Presently Installed	\$0.370	\$1.216	\$0.3267	\$0.6843
Required Systems	0.135	0.372	0.0931	0.1893
Total	\$0.505	\$1.588	\$0.4198	\$0.8736

E.2.13 Rendering Plants (33,56-65)

E.1.13.1 Industry Production

During 1968, approximately 875 rendering and fish reduction plants yielded an estimated 203,000 tons of fish meal, 2,400,000 tons of non-edible fat, and 2,400,000 tons of protein meal for a total of 5,003,000 tons of end products.(56) Although the value of these products is subject to a varying market, an average current price of approximately \$110 per ton gives an industry output value of approximately \$550 million. On April 1, 1969, there were approximately 920 rendering plants in the United States.

E.2.13.2 Industry Emissions

The bulk of emissions from the rendering process is odor with some dust. Dust emission is high in the fish reduction and bone rendering plants, but very low in the rendering plants handling poultry offal and meat trimmings.

Potential odor emission from the rendering process totals approximately 8.82×10^{15} odor units per year, as based on 10^9 odor units emitted per ton of feedstock input. Actual odor emissions are estimated to be 7.5×10^{15} odor units per year.

E.2.13.3 Degree of Control of Emissions

Most of the larger rendering plants have effective control and spend more for control equipment than do the smaller plants. It is estimated that 20 percent of the rendering plants have effective controls. Efficiency of plants with controls probably ranges from 99.99 percent to 50 percent.

E.2.13.4 Model Plant

Assuming that in 1968 the 203,000 tons of fish meal were produced by the 100 fish reduction plants, then average production was 2,030 tons at each plant. Assuming that the 4,800,000 tons of fat and protein meal were produced by 820 rendering plants (920 less 100), then the average total production was 5,853 tons at each plant.

Because information was available only for a plant producing 34,400 T/yr, this size plant will be used as the model.

Characteristics

The model plant will have the following characteristics:

Type process - - - - - - - - - - - - Continuous, dry rendering
Annual production - - - - - - - - - 34,400 tons
Gas temperature (from cooker) - - 212^{0}F
Emission type - - - - - - - - - - - Odors
Annual hours of operation - - - - 7,488
Annual emissions with no control - 6.24 x 10^{13} odor units
Average sales price per ton - - - $110

Control System

The control system on the cooker will consist of a surface condenser followed by an afterburner. The building air will be cleaned by a soda ash-water scrubber. Costs of control for the model plant are estimated to be:

	Low	High
Investment Cost	$150,000	$450,000
Annualized Cost	$ 30,000	$ 70,000

The above control system should have an efficiency of 99.9 percent in controlling odors.

Impact

The 34,400 T/yr produced in the model plant will yield about $3,784,000 in sales. The impact on the model plant from controlling emissions is:

	Low	High
Annualized Control Cost/Ton Product ($/T)	$0.87	$2.03
Annualized Control Cost as a Percent of Sales (%)	0.79%	1.85%

E.2.13.5 Estimated Industry Control Costs

By using the model plant costs, control costs for the entire industry can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost	$21.8	$65.4
Annualized Cost	$ 4.4	$10.2

Insufficient information precluded the division of control costs into those for required systems and those for systems presently installed. The amounts presented above are the total cost of control to the industry.

E.2.14 Sulfuric Acid(66-68)

E.2.14.1 Industry Production

Sulfuric acid production in 1967 amounted to 27,735,504 tons; of that total, 13,500,000 tons valued at $252,191,000 were shipped. The difference between production and shipments indicated that most of the acid produced serves as an intermediate product within the same establishments.

Sulfuric acid production is achieved by the contact and chamber processes. The former process accounts for 26,891,837 tons. The raw material consumed may be elemental sulfur, metallurgical gas, spent acid, pyrites, or refinery waste gas. Of the total number of 213 plants, 156 are contact plants and 57 are chamber process plants. Of the 213 plants, 132 are located within SMSAs.

E.2.14.2 Industry Emissions

Industrywide emissions for 1968 include approximately 590,000 tons of sulfur dioxide, approximately 31,000 tons of sulfuric acid mists and 23,000 tons of nitrogen oxides. The sulfur dioxide emissions represent a lack of complete conversion of sulfur dioxide to sulfur trioxide. The rate of conversion for both chamber and present contact plants was assumed to be 96 percent.

E.2.14.3 Degree of Control of Emissions

At the present time, some sulfur dioxide is being controlled in contact plants by carefully maintaining the catalyst at peak efficiency, and by monitoring and controlling the temperature and the oxygen/sulfur dioxide ratio in the converter. Acid mist emissions are also being controlled by scrubbers and mist eliminators, such as the fiber type of demister.

E.2.14.4 Model Plant

Almost 97 percent of the sulfuric acid is produced in single contact plants. Chamber plants account for the remaining portion of acid production.

Characteristics

The model plant characteristics are:

	Chamber	Contact
Annual output	15,000 tons	180,000 tons
Production rate	56 T/day	663 T/day
Annual hours of operation	8,750	8,750
Gas volume	6,200 acfm	40,000 acfm
Gas stream temperature	105°F	150°F
Emission type	Sulfur dioxide, sulfuric acid mists, and nitrogen oxides	Sulfur dioxide and sulfuric acid mists
Emissions with no control		
Sulfur dioxide	366 T/yr	6,250 T/yr

	Chamber	Contact
Acid mists	35 T/yr	410 T/yr
Nitrogen oxides	384 T/yr	None
Average price per ton	$18.70	$18.70

Control System

For the contact plant, double absorption--which achieves conversion of SO_2 to SO_3 at a 99.5 percent rate--will be assumed as the control technique. Fiber mist eliminators for sulfuric acid mists removal will also be included in the double absorption plant. These demisters can effectively remove mists at an efficiency of 99 percent.

Control costs for double absorption will include expenditures for two heat exchangers, an absorption tower, demisters, pump, pump tank, and acid coolers. Annual costs presented are the expenditures after credit for savings in raw materials. These costs include depreciation of investment at 10 percent and capital charges at 10 percent of investment. The control costs for the model contact plant are:

	Low	High
Investment Cost	$315,000	$630,000
Annualized Cost	$ 76,400	$161,000

The basic cost of a single contact plant(66) is $2,100,000; 15 percent of this was assessed for the low and 30 percent was assessed for the high investment costs(67) shown above.

With the control system on the above model plant, sulfur dioxide emissions will be reduced from 6,250 tons to 590 tons per year. Acid mist emissions will be reduced from 410 tons to 4 tons per year.

The control system assumed for the chamber process is a combination of the fiber mist eliminator (same as described above for the contact plant) and a catalytic afterburner. This system will reduce emissions of acid mists and nitrogen oxides.

The costs of control for chamber plants are:

	Low	High
Investment Costs	$34,000	$49,000
Annualized Costs	$20,600	$26,000

This control system will reduce the nitrogen oxide emissions from 384 tons to 76 tons per year, and acid mist emissions from 35 tons to 0.4 tons per year. No control is assumed for sulfur dioxide emissions in chamber plants. On a volume basis, chamber plant emissions are significantly smaller than for a contact plant. Chamber plant emissions range from 870 to 1640 ppm,(68) depending on the type of sulfur burned. Due to the diminutive size and the decline of chamber process production, the sulfur dioxide pollution potential is very low at the present time and will diminish in the future.

Impact

The impact on the model plants from controlling emissions is:

	Chamber		Contact	
	Low	High	Low	High
Annualized Control Cost/Ton Pollutant Removed ($/T)	$60.06	$75.80	$12.59	$26.54
Annualized Control Cost/Ton Acid Produced ($/T)	$ 1.37	$ 1.73	$ 0.42	$ 0.89
Annualized Control Cost as a Percent of Sales (%)	7.3%	9.2%	2.2%	4.8%

E.2.14.5 Estimated Industry Control Costs

By using the control costs from the model plants for both types of processes, control costs for the entire industry can be estimated as:

	Millions of Dollars	
	Low	High
Investment Cost	$50.8	$100.4
Annualized Cost	$13.0	$ 26.4

No attempt was made to differentiate between past and required control expenditures. The costs presented are total costs of control to the industry.

E.3 NONINDUSTRIAL CATEGORY

E.3.1 Incineration(5,18,69-76)

E.3.1.1 Production

In 1966 there were 265 incineration plants in the United States with an annual capacity of about 22.6 x 10^6 tons. Assuming that these plants operate near capacity, annual processing of wastes amounts also to about 22.6 x 10^6 tons. A distribution of plant sizes for 260 of the 265 plants is presented below:

Size - T/day	No. of Plants
<100	64
100-200	64
200-500	98
500-1000	29
>1000	5
	260

Of 185 plants responding to a questionnaire, 147 (79.5%) are within SMSA's, 21 (11.3%) are not, and the location of 17 (9.2%) cannot be determined.

E.3.1.2 Emissions

Annual emissions of particulates are 136,000 tons from 146 plants of 200 T/day or greater capacity.

E.3.1.3 Degree of Control of Emissions

Of 185 plants in a survey, 14 plants with a total capacity of 6,720 T/day (1,922,000 T/yr) have cyclones. The cyclones have an average efficiency of 55 percent and collect 31.4 T/day (8,980 T/yr) of particulates. Of the 185, 13 with a total capacity of 4,350 T/day (1,244,000 T/yr) have wet scrubbers. The scrubbers have an average efficiency of 88 percent and collect 32.6 T/day (9,324 T/yr) of particulates. All plants are assumed to have some type of settling chamber.

E.3.1.4 Model Plant

The model plant used in estimating control costs has two 150 T/day refractory lined multiple chamber incinerators. The refuse dries, ignites, and burns in the primary chamber of the incinerator. Combustion is completed in the secondary chamber where the combustion gases from the primary chamber are mixed with additional air at high temperatures.

Characteristics

The model plant has the following characteristics:

Type process	Two multiple chamber incinerators
Annual capacity	86,000 tons
Gas volume leaving each incinerator	107,000 acfm
Gas temperature leaving incinerator	1800^0F
Emission type	Particulates
Annual hours of operation	6,850
Annual uncontrolled emissions	730 tons

Control System

The control system consists of two settling chambers, two spray chambers, and one fabric filter. The gases leaving each incinerator enter a settling chamber where some particulate matter settles out. Each gas stream then enters a spray chamber where it is cooled from 1,800°F to 450°F. The two cooled gas streams join and pass to a baghouse where they are cleaned. The total gas volume entering the baghouse at 450°F is 90,280 acfm.

The estimated investment and annualized control costs for the model plant control system are:

	Investment		Annualized	
	Low	High	Low	High
Facilities presently installed	$ 18,000	$ 70,000	$ 2,400	$ 9,300
Required facilities	$166,000	$260,000	$54,900	$67,000
Model plant total	$184,000	$330,000	$57,300	$76,300

The costs for "Facilities presently installed" are those for the two settling chambers. All incineration plants in the United States apparently have settling chambers already on the incinerators, and, therefore, settling chambers are already installed on the model plant. The costs for "Required facilities" are those for the spray cooler system and the baghouse.

Installation of the proposed control system, which should have an efficiency of about 99.5 percent for particulates, will result in reduction of particulate emissions from 730 T/yr to about 4 T/yr.

Impact

The impact of the control system for the model plant is:

	Low	High
Annualized Control Cost/ton Particulate Collected ($/ton)	$75.62	$92.29
Annualized Control Cost/ton Refuse Burned ($/ton)	$ 0.64	$ 0.78
Annualized Control Cost/Capita ($/person)	$ 0.64	$ 0.78

These annualized control costs per ton are based on the cost figures for the required facilities shown in the preceding section. The numbers for "Annualized Control Cost/Capita" were calculated by assuming that 5.5 lb of refuse are collected from one person in a day.

E.3.1.5 Estimated Industry Control Costs

By using the model plant cost estimates, nationwide cost of control can be estimated as:

	Millions of Dollars			
	Investment		Annualized	
	Low	High	Low	High
Facilities presently installed	$ 5.4	$20.0	$ 1.1	$ 3.0
Required facilities	$43.3	$67.4	$14.1	$17.2
Total	$48.7	$87.4	$15.2	$20.2

The costs for "Facilities presently installed" include estimated costs for the settling chambers presently installed and estimated costs for wet scrubbers installed on 13 plants, but do not include costs for cyclones presently installed. The true costs for the wet scrubbers presently installed are not realistically represented here, since cost credit was given on the basis of the spray coolers specified in the model plant. The spray coolers have a lower efficiency than the average 88 percent efficiency of the wet scrubbers presently installed and thus have a lower cost.

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